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SUMMARY TECHNICAL REPORT
OF THE
NATIONAL DEFENSE RESEARCH COMMITTEE

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SUMMARY TECHNICAL REPORT OF DIVISION 19, NDRC

VOLUME 1

MISCELLANEOUS WEAPONS

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
VANNEVAR BUSH, DIRECTOR

NATIONAL DEFENSE RESEARCH COMMITTEE
JAMES B. CONANT, CHAIRMAN

DIVISION 19
H. M. CHADWELL, CHIEF

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By Chester C. Beckel (ASTIA)
Signature and Grade
Date 4 June 62

WASHINGTON, D. C., 1946

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NOTES ON THE ORGANIZATION OF NDRC

The duties of the National Defense Research Committee were (1) to recommend to the Director of OSRD suitable projects and research programs on the instrumentalities of warfare, together with contract facilities for carrying out these projects and programs, and (2) to administer the technical and scientific work of the contracts. More specifically, NDRC functioned by initiating research projects on requests from the Army or the Navy, or on requests from an allied government transmitted through the Liaison Office of OSRD, or on its own considered initiative as a result of the experience of its members. Proposals prepared by the Division, Panel, or Committee for research contracts for performance of the work involved in such projects were first reviewed by NDRC, and if approved, recommended to the Director of OSRD. Upon approval of a proposal by the Director, a contract permitting maximum flexibility of scientific effort was arranged. The business aspects of the contract, including such matters as materials, clearances, vouchers, patents, priorities, legal matters, and administration of patent matters were handled by the Executive Secretary of OSRD.

Originally NDRC administered its work through five divisions, each headed by one of the NDRC members. These were:

Division A — Armor and Ordnance
Division B — Bombs, Fuels, Gases, & Chemical Problems
Division C — Communication and Transportation
Division D — Detection, Controls, and Instruments
Division E — Patents and Inventions

In a reorganization in the fall of 1942, twenty-three administrative divisions, panels, or committees were created, each with a chief selected on the basis of his outstanding work in the particular field. The NDRC members then became a reviewing and advisory group to the Director of OSRD. The final organization was as follows:

Division 1 — Ballistic Research
Division 2 — Effects of Impact and Explosion
Division 3 — Rocket Ordnance
Division 4 — Ordnance Accessories
Division 5 — New Missiles
Division 6 — Sub-Surface Warfare
Division 7 — Fire Control
Division 8 — Explosives
Division 9 — Chemistry
Division 10 — Absorbents and Aerosols
Division 11 — Chemical Engineering
Division 12 — Transportation
Division 13 — Electrical Communication
Division 14 — Radar
Division 15 — Radio Coordination
Division 16 — Optics and Camouflage
Division 17 — Physics
Division 18 — War Metallurgy
Division 19 — Miscellaneous
Applied Mathematics Panel
Applied Psychology Panel
Committee on Propagation
Tropical Deterioration Administrative Committee

[redacted]

NDRC FOREWORD

As events of the years preceding 1940 revealed more and more clearly the seriousness of the world situation, many scientists in this country came to realize the need of organizing scientific research for service in a national emergency. Recommendations which they made to the White House were given careful and sympathetic attention, and as a result the National Defense Research Committee [NDRC] was formed by Executive Order of the President in the summer of 1940. The members of NDRC, appointed by the President, were instructed to supplement the work of the Army and the Navy in the development of the instrumentalities of war. A year later, upon the establishment of the Office of Scientific Research and Development [OSRD], NDRC became one of its units.

The Summary Technical Report of NDRC is a conscientious effort on the part of NDRC to summarize and evaluate its work and to present it in a useful and permanent form. It comprises some seventy volumes broken into groups corresponding to the NDRC Divisions, Panels, and Committees.

The Summary Technical Report of each Division, Panel, or Committee is an integral survey of the work of that group. The first volume of each group's report contains a summary of the report, stating the problems presented and the philosophy of attacking them, and summarizing the results of the research, development, and training activities undertaken. Some volumes may be "state of the art" treatises covering subjects to which various research groups have contributed information. Others may contain descriptions of devices developed in the laboratories. A master index of all these divisional, panel, and committee reports which together constitute the Summary Technical Report of NDRC is contained in a separate volume, which also includes the index of a microfilm record of pertinent technical laboratory reports and reference material.

Some of the NDRC-sponsored researches which had been declassified by the end of 1945 were of sufficient popular interest that it was found desirable to report them in the form of monographs, such as the series on radar by Division 14 and the monograph on sampling inspection by the Applied Mathematics Panel. Since the material treated in them is not duplicated in the Summary Technical Report of NDRC, the monographs are an important part of the story of these aspects of NDRC research.

In contrast to the information on radar, which is of widespread interest and much of which is released to the public, the research on subsurface warfare is largely classified and is of general interest to a more restricted group. As a consequence, the report of Division 6 is found almost entirely in its Summary Technical Report, which runs to over twenty volumes. The extent of the work of a Division cannot therefore be judged solely by the number of volumes devoted to it in the Summary Technical Report of NDRC: account must be taken of the monographs and available reports published elsewhere.

Hampered and confused by the unfamiliar restrictions of military security, many civilian scientists engaged in NDRC research found themselves particularly hindered by the lack of opportunity for free and open consultation. This was particularly true for Division 19 under the leadership of Harris M. Chadwell. Few even in the military services knew of its existence, and still fewer knew of its operations. Working closely with the Office of Strategic Services, it was devoted to the development of instruments for sabotage and espionage in enemy-held territory—a subject not widely discussed even in time of peace.

Since few men were cognizant of the Division's activities, this Summary Technical Report, prepared under the direction of the Division Chief and authorized by him for publication, will have only a very limited distribution. It is regrettable that this is necessary and that wider recognition cannot be given to the men of the Division and its contractors. Their contributions made possible to a large extent the successful operations of their country and its allies in the war of the underground. Their efforts were those of men of high integrity, imagination, and competence, cooperating loyally and brilliantly in the defense of their country.

Vannevar Bush, Director
Office of Scientific Research and Development

J. B. Conant, Chairman
National Defense Research Committee

[redacted]

FOREWORD

In its volume of the Summary Technical Report, Division 19 is a special case among the divisions of NDRC. Throughout its existence this division did not conform to the established practice of distributing reports; it received very few problems from the Army and Navy through the usual channels and limited its activity almost exclusively to problems submitted by an intimate and informal liaison with the Office of Strategic Services and the British liaison officers assigned to that group. Since the true nature of the work done by OSS has been well publicized, it can be logically inferred that the developments produced by Division 19 under the ambiguous title *Miscellaneous Weapons* were connected with the underground organizations established in Europe prior to D-day, with special attention given to sabotage and unorthodox warfare. The unusual handling of the division's reports is thereby explained.

During the course of its existence, however, the division, by accident rather than design, did work on several problems of value and interest to the older and more orthodox branches of the Armed Services. In such instances, there was complete exchange of information on a very informal basis with the Service groups concerned, and guidance and valuable information were thereby provided for the division's contractors. It is hoped that the division has assisted the research programs of the Army and Navy.

The largest contract under the division was with Ford, Bacon, and Davis, Inc., for the operation of a central laboratory known as the Maryland Research Laboratories [MRL] located near Washington. Members of the staff of that laboratory contributed, in one way or another, to the development of most of the devices described in this volume and they cooperated wholeheartedly with other contractors of the division.

Throughout the complete program of Division 19, Dr. Warren C. Lothrop served as Technical Aide. The major part of this volume of the Summary Technical Report was compiled by Dr. Lothrop. Chapters 18, 19 and 20 were written by Mr. S. Reid Warren, Jr., of the Moore School of Electrical Engineering of the University of Pennsylvania, where the devices described in these chapters were developed. To the authors I wish to express my gratitude.

It was originally decided that there should be no Summary Technical Report for Division 19, but, in view of the past exchange of information and the fact that many of the devices were known to the older Services as a result of the above relationship, it was finally decided that those parts of the division's work which could properly be called legitimate should be recorded and should constitute its Summary Technical Report. From this point of view, the four parts of this volume have been prepared.

Unfortunately, in comparison with the other volumes of the STR, the usefulness of the material is limited, since microfilming of the references contained in the various bibliographies has been omitted. This decision was made by high authority in order to keep to a minimum all extraneous information in the division's reports and to keep small the circle of people who are thoroughly acquainted with the unorthodox aspects of the activity. However, if any part of this volume should be of special interest to some Service group, it is believed that there will be little difficulty in arranging for access to specific portions of the division's files or the files of the Strategic Service Unit, War Department, by the appropriate personnel. Many of the reports to which reference is made are already in the hands of those groups of the Army and Navy who are primarily concerned.

Despite these limitations, it is hoped that this volume will be of value, as much for the description of unsuccessful work as for the description of devices which, in production and field use, proved successful in many special operations.

H. M. Chadwell
Chief, Division 19

This volume, like the seventy others of the Summary Technical Report of NDRC, has been written, edited, and printed under great pressure. Inevitably there are errors which have slipped past Division readers and proofreaders. There may be errors of fact not known at time of printing. The author has not been able to follow through his writing to the final page proof.

Please report errors to:

JOINT RESEARCH AND DEVELOPMENT BOARD
PROGRAMS DIVISION (STR ERRATA)
WASHINGTON 25, D. C.

A master errata sheet will be compiled from these reports and sent to recipients of the volume. Your help will make this book more useful to other readers and will [illegible]

CONTENTS

PART I

WEAPONS

During World War II, as never before, science was enlisted for the development of new weapons of warfare utilizing many kinds of scientific principles. The results were remarkable, and warfare thereby assumed previously unthought of tactical aspects. Concurrent with this was the acceptance by the Army and Navy of ideas of a novel and unorthodox type. The most spectacular and larger contributions of OSRD to the military are found elsewhere in the Summary Technical Report. Very frequently these were of a large scope.

The work of Division 19 described in this part on weapons, while retaining the novel and unorthodox features to an enhanced degree, resulted in no discovery which could rank with radar, the atomic bomb, or the proximity fuze in its great effect on military operations. Nevertheless, a number of small and useful devices were developed primarily of value to the individual soldier or small groups, in operations exemplified by commando raids and scouting parties. In this more limited and very specialized field, the weapons described in Part I are believed to have real value and to bring close to the individual results of modern technological development. A neglected field was thereby opened and partly explored.

Considerable imaginativeness has been shown in these developments, and this demands an equal imaginativeness on the part of potential users. The very unorthodox nature of some of the devices will of necessity mean that the field of hand application is a narrow one at best, but this is not to say that in that narrow field their value may not be of the highest degree to a given individual in a given situation. In such cases it may far outweigh the rather limited demand which might be foreseen and because of which Army and Navy procurement might, with logic, hesitate.

To those who have been close to the development of these weapons, it has always seemed that they might well supplement for surprise use the more orthodox devices now issued to special troops. Only one of the developments described in Part I may have a broader scope; this is the impact spherical hand grenade known as Beano and described in Chapter 3. For the most part the weapons are explosive in nature, there being only one which has a truly incendiary action among them; this is the oil slick igniter described in Chapter 2. Others such as Beano loaded with white phosphorus (see Chapter 4) and slow burning explosives (see Chapter 6) lie intermediate between explosive and incendiary devices. However, without exception all the weapons in their present state are of a size suitable for use by a single person and should probably be presented as items for individual issue to special scouting or raiding parties.

The groups in the Army and Navy who have been acquainted with these devices and who would appear to find them of value would include particularly the Army Ground Forces, the Corps of Engineers, the Chemical Warfare Service, the Ordnance Department, the Bureau of Ordnance, and the Marine Corps.

Chapter 1

ROCKET LAUNCHERS

1.1 INTRODUCTION

The striking power of an individual foot soldier has been greatly enhanced by the development of portable rocket weapons of which the M6A3 or Bazooka of the Americans and the PIAT gun of the British are the foremost. Each of these, of course, is provided with its launcher and, as generally used, is a shoulder weapon. That there may be occasionally a need for firing as a booby-trap or delayed action device is also well recognized and has been indicated in publications of the Ordnance Department and the Corps of Engineers. In this case, it is customary to use, as the launcher, the original packing tube in which the rocket round is delivered to the field. A small amount of work on this application was done by the division and is discussed below.

The Bazooka is, however, not a very formidable rocket when compared to those used by and against ships and aircraft. It would seem logical therefore to make one of these heavier and more destructive rounds available to the individual soldier for his use against some specially selected and unapproachable target. This idea resulted in the perfection of a portable, re-usable, but expendable launcher small and light enough to be carried by an individual, and simple enough to be erected and fired easily, either manually or by trip wire or time delay fuze (see Chapter 9). This work using the 3.55-in. *spin stabilized rocket* (SSR) developed at California Institute of Technology [CIT] under Division 3 of NDRC is the subject of Section 1.3.

1.2 LAUNCHING M6A3 BAZOOKA ROCKETS FROM THEIR CONTAINERS

For the use contemplated, three separate minor developments were required: a simple unadjustable sight representing a separate item of equipment, a trip wire firing system, and a time delay firing system.

1.2.1 The Sight

This consisted of thin sheet steel 8 in. long, 2¼ in. wide, and 2⅛ in. high, dimensions which fitted the standard tubular cardboard containers in which the 2.36-in. Bazooka rounds were issued to the field. Mounted laterally on this base was a bead and pinhole sighting system analogous to the standard rifle sight, but ending in a mirror, of either glass or polished metal, mounted obliquely to allow convenient observation of the target during final location of the cardboard carton in the ground. The sight as finally produced by the Office of Strategic Services was rigidly constructed to provide an accurate range of 100 ft, a distance selected as optimum from the standpoint of rocket performance and operational needs. It would be possible to alter this range slightly but not significantly.

The performance for this sight is illustrated by Table 1, which was obtained from firing five live rounds of M6A3 ammunition from their packing containers after aiming with the reflecting sight.[2] The

TABLE 1. Performance of M6A3 sight.

Shot No.	Vertical deviation inches	Lateral deviation inches
1	42 low	20 right
2	8 low	0
3	15 high	8 left
4	0	0
5	25 low	0

target was at a distance of 95 to 97 ft, the wind velocity was 2 mph or less, and the temperature was 78 F. Averaging of the data indicated a center of impact falling 12 in. below and 3 in. to the right of the aiming point, an aberration which was not considered serious.

1.2.2 Trip Wire Firing [1]

The standard Bazooka launcher is equipped with dry cells which provide electric firing of the round. For booby-trap use, batteries were unreliable because in the indeterminate period of inactivity following the setting up of the trap they might go dead. In their place was substituted a simple, mechanically operable electric magneto which was found by test to deliver a current sufficient to insure firing the round and which, of course, had an indefinite shelf life. The recommended, standard Navy Mark 22 Magnavox magneto was connected to the wires from the electric squib located in the tail of the rocket motor and then attached to a trip wire suitably mounted across a road or trail. A sharp pull on the trip wire was sufficient to turn over the magneto and deliver to the electric squib a surge of current adequate for firing it.

1.2.3 Time Delay Firing [1]

In cases where it was desirable to aim and plant the round, and then to fire it at some future preselected time, a different but equally simple system was supplied. The electric squib was removed from the motor and a short length of safety fuze, bearing several slanting cuts, was introduced into the propellant charge. The other end of the fuze was connected in the standard manner to a time delay Pencil having a spring snout (see Chapter 9 and Section 11.3.3).

1.2.4 Operation [1]

The rocket round in its original packing carton could be set up in some concealed place and trained on a spot in a road, for example, or on a nearby target which could not be closely approached. The procedure was to embed the tubular carton, the closed ends of which had been cut off to make it an open tube, in the earth, training it on the target with the aid of the sight which was laid on top of the tube. In order to avoid disturbing the tube after final sighting, it was found best to have the rocket with safety pin removed in the tube before final aim was taken and the sight removed. It was important that the tube be solidly embedded in soil, which should preferably not be sandy. When 14 rounds were fired under these conditions at a target 95 ft distant and with the sight fixed at 1 degree elevation, all fell within a 5-ft radius circle and 50 per cent in an 18-in. circle, the center being the point of aim (see Figure 1).

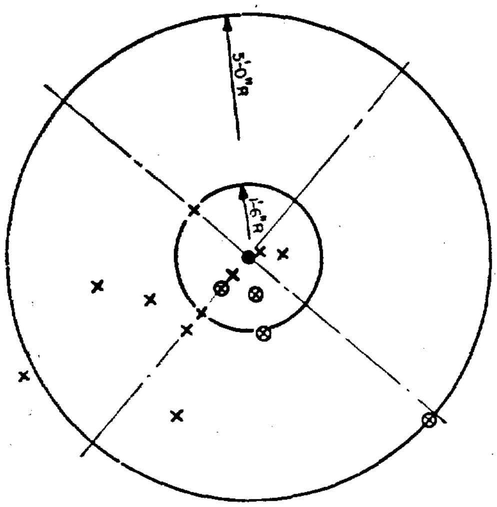

FIGURE 1. Dispersion — M6A3 rockets.

1.3 ROCKET LAUNCHER FOR 3.55-INCH SSR [3,8]

Upon the advice and through the cooperation and support of Division 3 and their contractor CIT a selection of a rocket more powerful and effective than the 2.36-in. Bazooka was made. The choice fell on the 3.55-in. *spin stabilized rocket* (SSR) which Division 3 had developed to satisfy a special Navy requirement.[5,6] In the following discussion only the briefest details of this special rocket are recorded, since it was not a development of Division 19. More thorough treatment is given the launcher and its adaption to the firing of Bazooka rounds (Section 1.3.3).

1.3.1 The Round [3]

The ammunition for which this launcher was designed was the Navy 3.55-in. SSR. The following data apply:

Length	24.35 in.
Diameter, bourrelets	$3.500 \begin{matrix}+0.000\\-0.010\end{matrix}$ in.
Weight	24 lb
Payload	14.6 lb
Explosive charge (TNT)	1.5 lb
Maximum velocity	760 ft per sec
Fuze	Nose fuze Mark 100 Mod. 0 (Superquick with 0.05-sec delay)
Motor burning distance	230 ft at 70 F.

Firing: electric — through body and the insulated contact ring.

Effective range for this type of use: 1.000 yd or less.

Unavoidable deviation: about 6 mils for moderate ranges.

Lateral deflection for ranges under 1,000 yd: about 30 mils left.

The next to the last datum above is a measure of the inherent inaccuracy of the rocket, for rockets do not possess the reproducibility of artillery shells. The final datum is a deflection inherent in all spin stabilized rockets and is the result of gyroscopic effects.

The following examples are quoted to indicate the power of the round: with fuze set for 0.05-sec delay, the round penetrated a 6.5-ft thick sandbag target and burst on the other side; with a 10-ft thick target it burst inside; set for the same delay, a round hitting

a 24-in. thick concrete wall burst inside the wall and blew out craters 36 to 48 in. both in front and back.

1.3.2 The Launcher [3]

This was designed to be as light as possible, extremely portable, and to serve as container for the round and all accessories. Pertinent data are contained in the following tabulation:

- Weight of launcher with one round and all accessories: 40 lb.
- Weight of launcher with all accessories: 16 lb.
- Length of launcher including end caps: 32 in.
- Mount: 3 folding legs, the rear spade-shaped, the front legs pointed.
- Sight: peep sight with front bead fixed and rear peep hole on an arm adjustable for ranges up to 1,000 yd.
- Firing: electric, using Navy Mark 22 magneto firing key.

The sight and firing are similar to those of the Bazooka described in Section 1.2. The launcher was made of aluminum alloy for lightness and strength, and was treated to resist corrosion. In the complete assembly it contained one round, a 25-ft firing line, a magneto switch, time Pencils, and trip wire. When the legs and sight were folded, the compact unit was easily carried on a light packboard, from which it was quickly removed and implaced for operation. The device was considered as expendable, although it was found in actual tests to be capable of firing over 100 rounds without visible deterioration.

The sight and elevation adjustments in the legs were designed to allow use of the rocket in the intermediate ranges where its accuracy was good. Such ranges corresponded to a reasonably flat trajectory at a maximum elevation of 8 degrees, hence the accuracy was better against vertical than horizontal targets. This was at least equal to the accuracy obtained with any launchers from which the 3.55-in. rocket had been fired. The observed dispersions corresponded to mean deviations of 6 or 7 mils at the ranges tested (apparently a characteristic of the round at its state of development).

1.3.3 Operation [3]

The launcher could be quickly disassembled from the pack, and by means of the folding legs set up pointing roughly in the correct direction. Final aim was secured by elevation and fine traverse adjustment incorporated in the rear leg mechanism. The feet of all three legs were sharp and pointed, so that a good hold could be secured in the ground and the launcher firmly planted. Even so, it was found neces-

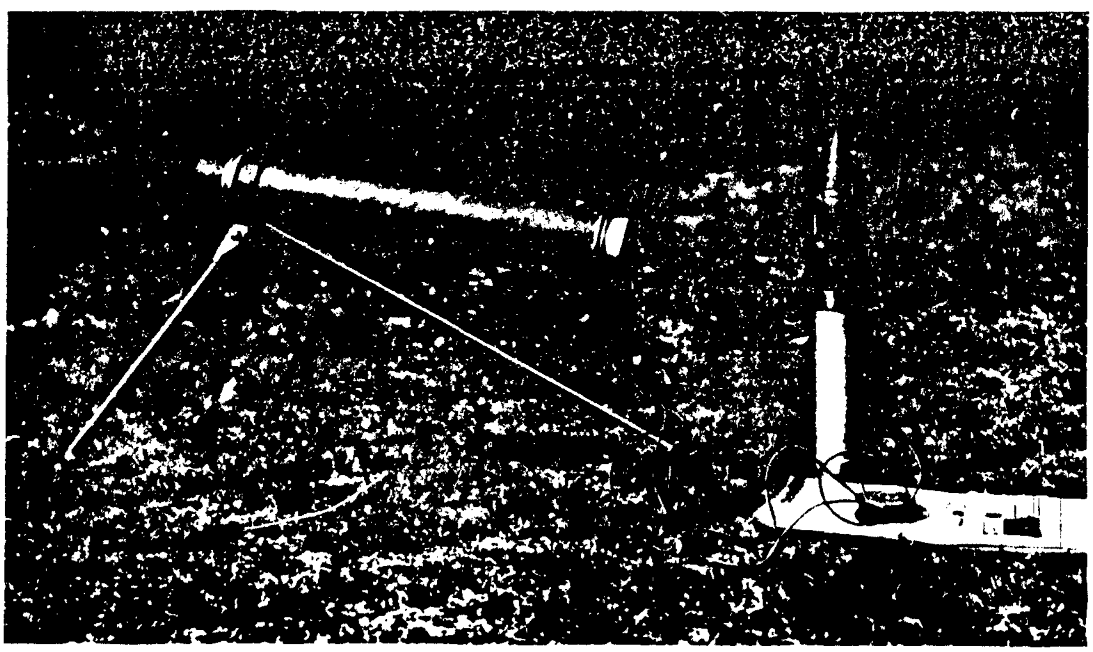

FIGURE 2. Launcher assembled with firing line and magneto and round.

FIGURE 3. Layout of launcher and round before assembly to packboard.

sary to weight the launcher to prevent its being upset by the blast from the rocket. This was conveniently and simply accomplished by including, in the accessory kit, a canvas and glass cloth bag which was filled with about 20 lb of available ballast, such as rock and sand, and suspended by a strap passing over the launcher tube near the front sight. When the launcher was thus weighted, repeated shots could be fired without extensive readjustment of the aim. The detachable rear leg was spade-shaped to assist in obtaining the needed ballast. The rockets were loaded and all adjustments were made at the rear end of the launcher.

Firing was accomplished either by trip wire, manual operation, or by time Pencil. Details of the first two of these methods (see Section 1.2) are not included. The time delay firing, however, differed from the procedure given in Section 1.2.3, in that the time delay Pencil was connected directly to the firing magneto and the latter was operated by impact of the Pencil striker. This change was necessitated by the requirement in the case of this rocket of electric firing at all times.

1.3.4 The Bazooka Adapter [4]

It was thought desirable that the launcher for the 3.55-in. SSR also be able to fire the more readily available Bazooka 2.36-in. rockets. Thus the launcher's usefulness would not cease when the few rounds shipped with it to the field had been exhausted. An arrangement was worked out consisting primarily of three aluminum tubes of such diameter that, when inserted into the launcher tube, they provided three guiding rails for the smaller round. Three slots at each end of the launcher tube served to fix these rails in position and their attachment or removal was possible in a few seconds.

The only other special provision was a central peep-sight hole (not offset as was the one on the launcher which compensated for the lateral drift of the SSR) and a spring clip on the ungrounded firing contact for attachment to the Bazooka's firing wire.

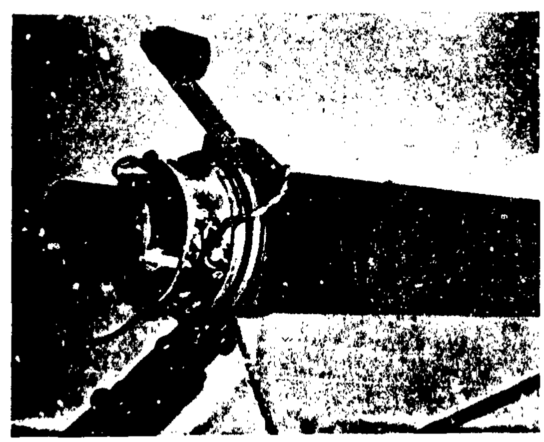

FIGURE 4. Breech of launcher showing rails and contacts with 2.36-in. rocket partly inserted; method of making electrical contacts with the round; and the two peep-sights.

In actual use with Bazooka rounds, some bad yawing occasionally was encountered. This was perhaps not unexpected with this rocket [7] and was entirely corrected by filling the empty cone of the shaped charge with plastic explosive or cast pentolite. This, at the same time, increased the charge from

0.5 lb to 1.3 lb and gave a range at 8 degrees elevation of about 130 yd with good accuracy. It was realized, of course, that the penetrating characteristics of the original round had been sacrificed and the procedure at best was makeshift. Nevertheless, when it is noted that the complete modified launcher weighed slightly less than the Bazooka launcher, could be operated by one man, and could be used to fire rapid and successive shots without re-aiming, consideration of this use is warranted.

Chapter 2

OIL SLICK IGNITER (NO-234)

2.1 INTRODUCTION

At the request of the Navy, Division 19 was asked to develop a scatter bomb which, when released from an airplane traveling at speeds up to 300 mph and at altitudes of under 1,000 ft, would reliably ignite floating oil slicks. The operational requirement was jointly framed by officers in the Bureau of Ordnance, the Bureau of Aeronautics, and the Office of the Commander in Chief. It was also desired that the oil slick igniter be capable of igniting standing pools of oil on land, with the oil in either case being devoid of volatile constituents. So-called Navy Special, Bunker C, and crude oils were accepted as suitable.

Operationally, it was thought that reconnaissance planes equipped with a few igniters of this type would be most useful in destroying torpedoed ships and tankers floating helplessly on the sea surrounded by the oil slick liberated from their opened tanks. The land use would be more limited and would be confined to those rare instances where a large storage tank had been ruptured and had released pools of standing oil.

Both problems were met by the development of small cardboard cartons containing a fuel charge which was ignitable, either by contact with water or by a secondary fuze system. The former was known as the City Slicker and was either *rectangular* (CSR) or *triangular* (CST), while the latter, because of its function on either sea or land was dubbed *Paul Revere* (PR). All are described in this chapter,[9] from which it will be seen that the PR differed from the CSR only in the addition of the separate fuze system.

2.2 FUEL CHARGE [1]

Two prior developments by the British were known to NDRC workers. These were both primarily of a defensive type and had been produced to ignite oil slicks which were to be liberated by underwater pipes in the face of an attempted invasion of Britain. The first of these was the so-called Cough Mixture (KOFQR), an alloy of sodium and potassium suspended in benzene in a frangible glass container. This, on impact with the sea, broke, liberating the contents which were spontaneously inflammable when mixed with water. The other development centered on the use of calcium phosphide which was similarly employed.[2,3]

Neither of these appeared likely to satisfy the American offensive requirements, largely because of their uncertain behavior against the oils specified, and a different igniting charge was therefore obtained. This charge was based on a product of the Permanente Metals Corporation known as Permanente Mix which closely resembled the standard "goop" used in large quantities by the Chemical Warfare Service for filling the M-74 and M-76 incendiary bombs. It consisted of a paste of crude, finely divided magnesium (with magnesia and carbon) in Stoddard Solvent-asphalt. This was dried to 85 per cent ± 5 per cent solids, 3.5 per cent ± 0.5 per cent asphalt, and 11.5 per cent ± 0.5 per cent Stoddard Solvent, then screened through a 6-mesh 0.135-in. screen. The dried solid "goop" thus obtained contained as a minimum 40 per cent metallic magnesium, and was close to the limit of spontaneous reaction with moist air.

Dried iron oxide from mill scale was ground 100 per cent through an 80-mesh screen to contain at least 65 per cent iron and no more than 0.3 per cent moisture. The dried "goop" was mixed with it in the proportion of 85 per cent by weight of "goop" and 15 per cent iron oxide. In final form the Permanente Mix was a dark brown mealy powder, very sensitive to water vapor and spontaneously inflammable with either salt or fresh water.

2.3 IGNITION [1]

However, in practice it was found desirable in the interest of quick ignition on contact with water, to provide a booster. This took the form of a small cloth bag of calcium carbide situated in the center of the fuel charge and close to the water inlet opening of the carton. Penetration of water to the carbide was quick and resulted in an immediate and rapid evolution of acetylene with attendant heat release which was sufficient to raise the speed of ignition of the main charge to less than 25 sec. This type of ignition system was common to all three devices (CSR, CST, PR).

For land use of PR, a secondary ignition system was provided. This consisted of an external celluloid case cemented to the side of the carton and communicating with the main fuel charge by means of an inserted celluloid window. The filling of this case was a

hot burning mixture of 88 parts potassium perchlorate, 11 parts paraffin, and 1 part petroleum coke.[4] Ignition of this first fire mixture was brought about by the action of a time delay Pencil (see Chapter 11) equipped with an incendiary matchhead ending.

2.4 CONSTRUCTION

2.4.1 Of the CST

The construction of the CST can be seen from Figure 1. Because the triangular unit floated on its side with either a flat surface or an edge projecting a short distance out of the water, the ignition hole was placed at the end, in the center. Closure of this port (providing for the eventual entrance of water) was made with a glued-on brass tear tab having a perforation through which a pull ring and string were threaded. The tab was not glued directly to the carton but to a cardboard ring that could be torn without damage to the package wall.

The carton was provided with a corrugated paper liner, inserted with the flukes outward, giving adequate buoyancy to the packet and contributing to the formation of a residual charred shell that sustained the burning charge in the water and kept it from dispersing. Asbestos liners were inserted on all three sides between the corrugated liner and the carton to prevent the flame from shooting upwards and to direct it along the surface of the water and hence against the oil slick. The igniter bag contained about 25 g of ¼-in. calcium carbide wrapped in a 6-in. square of cheesecloth and a similar square of absorbent paper which promoted the absorption of water and hence the reaction of the carbide.

The carton itself was cut by a special die from the superior grade of jute board developed for the Quartermaster K-Ration and for Ordnance stores. The style of box, with an outside glue flap and a special seal, conformed to the best principles of moisture-proofed cardboard containers.

2.4.2 Of the CSR and PR

Figure 2 illustrates the construction of these more elaborate units. The ignition hole, sealed with the same brass tear tab used in the CST, was here at the center of one of the narrow sides of the rectangular package, which floated on one of its wide sides. Asbestos liners were provided on the two wide sides to direct the flames downward along the surface of the water, but there was no asbestos along the narrow sides. The corrugated cardboard liner in this case had two 1-in. holes which coincided with the two narrow sides of the carton. Thus one hole was adjacent to the water-admission hole that was covered by the tear tab. In the finished munitions, a porous pasteboard tube 1-in. in diameter fitted into the two holes provided in the corrugated liner, and held a calcium carbide igniter-bag in place close to this entrance hole.

In the case of the PR, on the narrow side of the carton opposite the tear tab a celluloid case was glued to the outer surface. This case contained a central well for inserting a time delay (SRI) and on either side of this, chambers filled with the fast burning perchlorate mixture already mentioned in Section 2.3.

2.5 MANUFACTURE[4]

Two semi-production experiences proved the extreme sensitivity of the igniters to atmospheric humidity. This difficulty occurred not only in the original production of the fuel charge, the deterioration of which could have been foreseen, but also in its subsequent handling during loading procedures and in storage, where resistance of the carton to slow moisture penetration over long periods was small. The latter proved a difficult technical problem but was eventually solved by using proper glues and by lacquering and waxing. This susceptibility on the part of the oil slick igniters did not lead to a dangerous condition, rather, duds resulted which while a nuisance and certainly undesirable were by no means so serious. Nevertheless, with adequate inspection during manufacture there is no reason to expect anything but a perfect product.

The various steps in manufacture included gluing of the sides and ends (and in the case of the PR, affixing of the celluloid case), which was done in one operation using Dewey and Almy adhesive No. 737, and drying the freshly glued cartons under weights on suitable wooden forms. The hole in the celluloid case of the PR, through which the time delay Pencil was inserted, was then sealed with a small wad of Presstite Fuel Tank Sealer SS-50.

The dried cartons were then dipped twice in an 18 per cent solution of vinylite (VMCH resin) in hexone (60 parts) and toluene (40 parts) and placed to dry on specially made racks in a current of warm air for two hours.

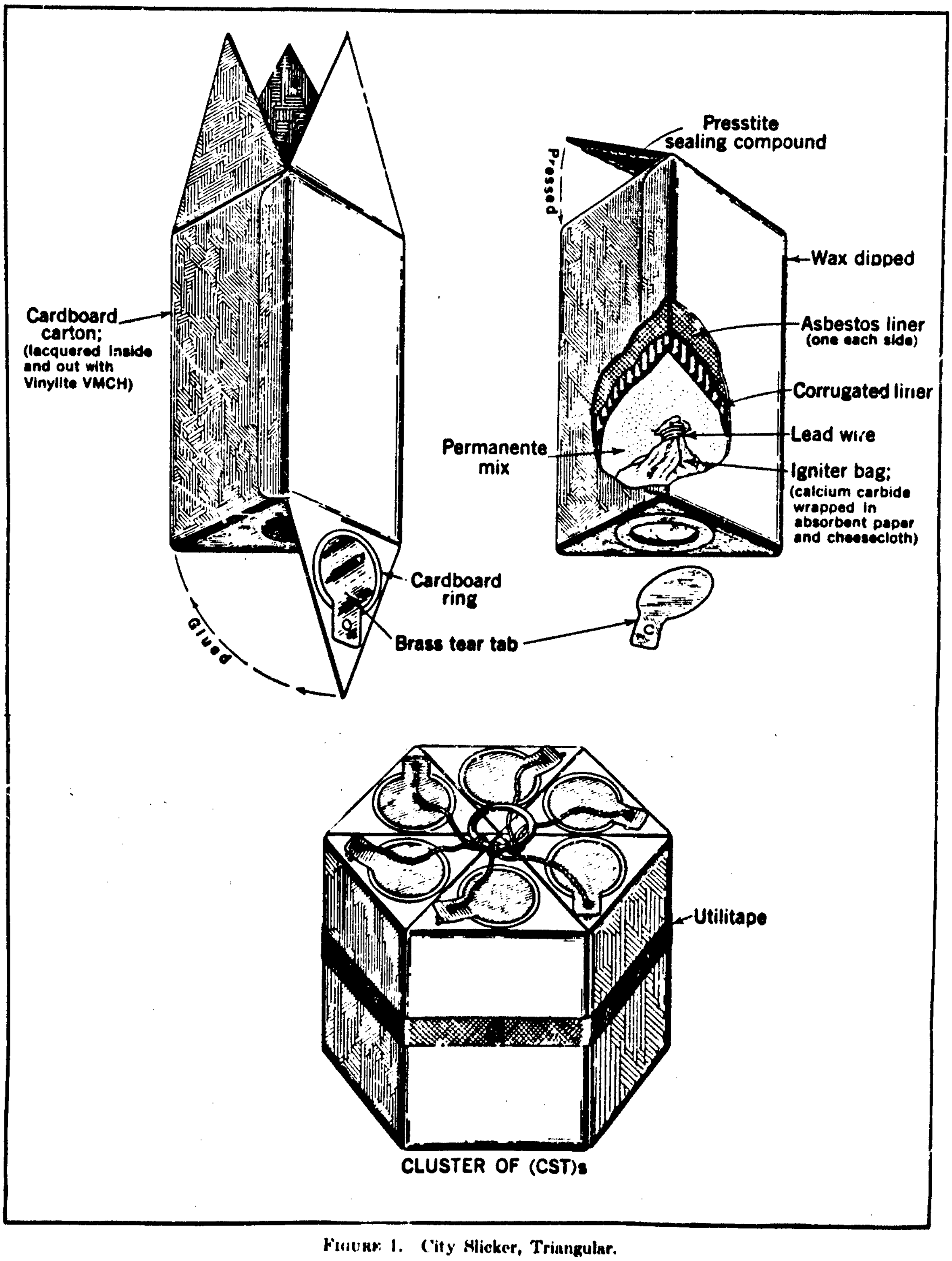

FIGURE 1. City Slicker, Triangular.

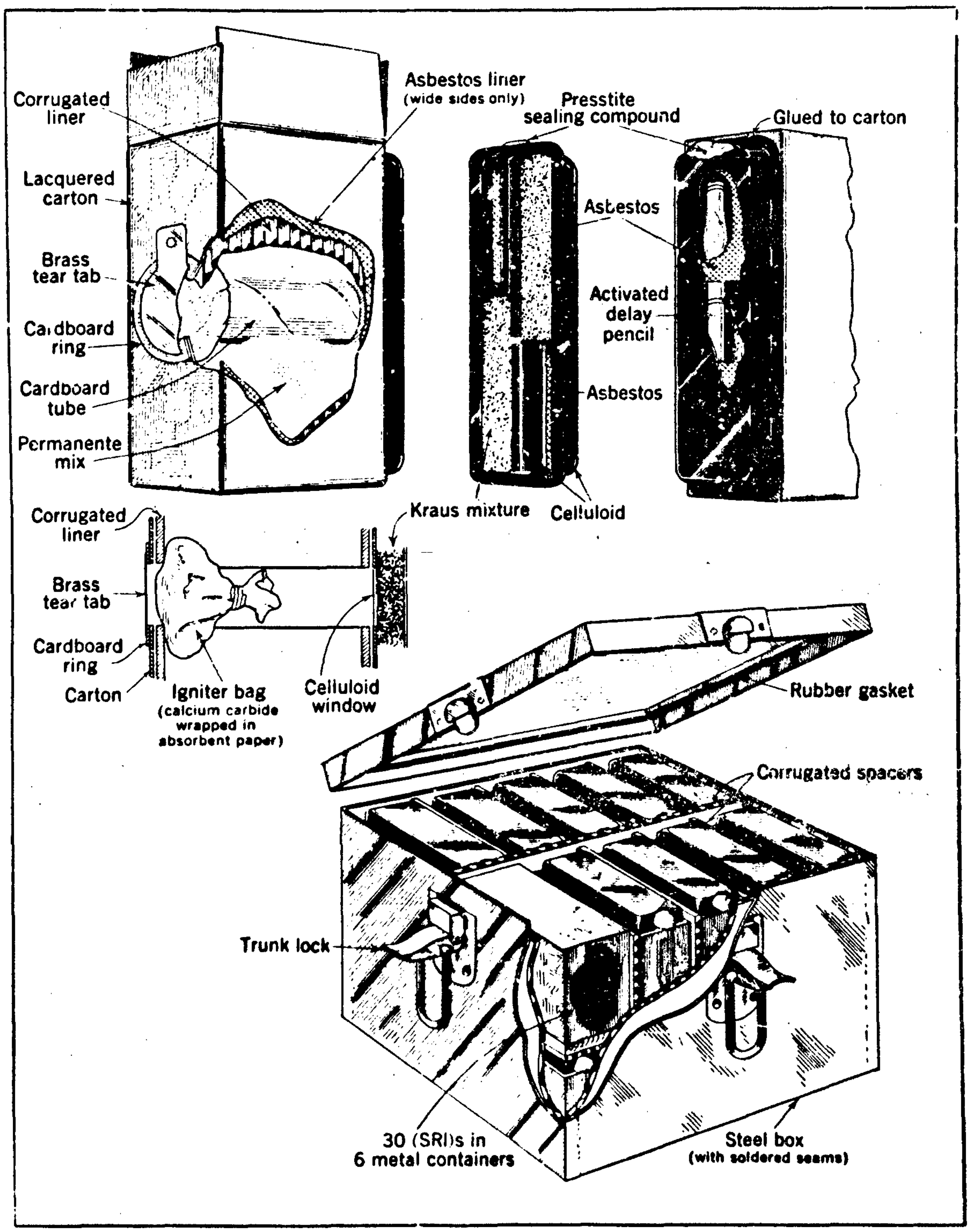

FIGURE 2. The Paul Revere.

The loading had to be done under atmospheric conditions which would insure both safety in the handling of the Permanente Mix and complete protection from any deterioration of either this material or the calcium carbide during the very brief period of exposure involved. The cartons were inspected for any irregularities which might interfere with the subsequent sealing operation, and the corrugated liners and asbestos liners were inserted, followed by the fuel charge and lastly the calcium carbide bag. (In loading the PR unit the carton was first filled to within about ½ in. of the side holes, the tube containing the calcium carbide bag was inserted, and the filling with Permanente Mix was then completed.)

The filled cartons were then sealed with Presstite Extruded Fuel Tank Sealer SS-50 under pressure, painted on the exposed edges with a liberal portion of Glyptal Cement No. 1276 and dried with that end up for 3 hours. The final operation was to dip each carton individually in Darex Thermoplastic Coating BM16 at 120 C ± 5 C.

The finished units, thus obtained, measured as follows: CST: length 6⁵⁄₁₆ in., width 3⅝ in., weight 0.88 ± 0.06 lb; CSR and PR: length 5¾ in., breadth 4 in., thickness 2¼ in., weight 1.16 lb ± 0.06 lb.

It should be noted that the lacquering finish applied was impervious to the oils in the fuel charge, while the exterior wax coating was impervious to water vapor.

2.6 INSPECTION TESTS [1]

To insure a reliable product and to provide test procedures suitable for quality control, it was necessary to devise simple and routine tests for the use of the manufacturer and the Service Procurement Office. The test for function was naturally the first and most important of these. One per cent of each 1,000 units was tested in water to meet the specification of positive ignition in less than 25 sec and continued burning time of at least 1 min. This was therefore a conclusive test of the finished product but was of no value in locating unforeseen troubles before they had affected quality.

More valuable from a practical point of view was the so-called Lily cup test. A mixture of 30 g of Permanente Mix, 10 g of ¼-in. calcium carbide and 15 cc of water in a paper cup was timed for first ignition. A fairly accurate estimate of the reactiveness of the fuel charge was thereby secured, but an exact correlation between the timings given by this test and the performance of the igniters in the first test was never deduced.

A third test of great value and simplicity determined the extent of deterioration of the calcium carbide in a given igniter. Repeated observation showed that any moisture capable of penetrating to the interior of the carton preferentially attacked the carbide with the result that lumps disintegrated into dust. Accurate measurement of this dust was simple and indicated the extent of moisture penetration. While the amount of carbide present was several times the minimum needed, loss of more than 10 per cent of that originally present was considered serious and an indication that the elaborate waterproofing treatment with lacquers and wax was inadequate.

In the case of the PR units an additional test was made to insure the quality of the fast burning mixture contained in the celluloid case. For this purpose, the total burning time of the case and its filling was specified to fall within 20 to 30 sec.

Exhaustive trials were run on the finished units under a variety of humidity and temperature exposures to prove the adequacy of the moisture-proofing coatings. Of all these, that test in which the individual units were left in a stream of running tap water proved the most severe. In the CST, CSR, and PR units just described, even this test was passed without loss of efficiency after a week's trial. The test as applied in manufacture specified that 1 per cent of the production units be floated in pans of running water for 48 hours and the carbide and special PR tests described immediately above were then made.

2.7 PACKAGING

Figures 1 and 2 indicate the way in which the CST and PR, or CSR, units were supplied to the field. The CST's were grouped in a hexagon contained in a streamlined, cylindrical bomb casing adapted for loading on the 100-lb stations of Army or Navy planes. The CSR and PR units were packed either in rubber gasketed steel boxes, similar to the one illustrated in Figure 2, or in the cheaper and more available 0.50-cal. M2 steel ammunition cases. The common feature of all three types of package was their watertightness until the moment the incendiaries operated.

2.8 OPERATION FROM AIRCRAFT [1]

The CST was designed for clustering in the bomb case. The details of the construction, operation, and

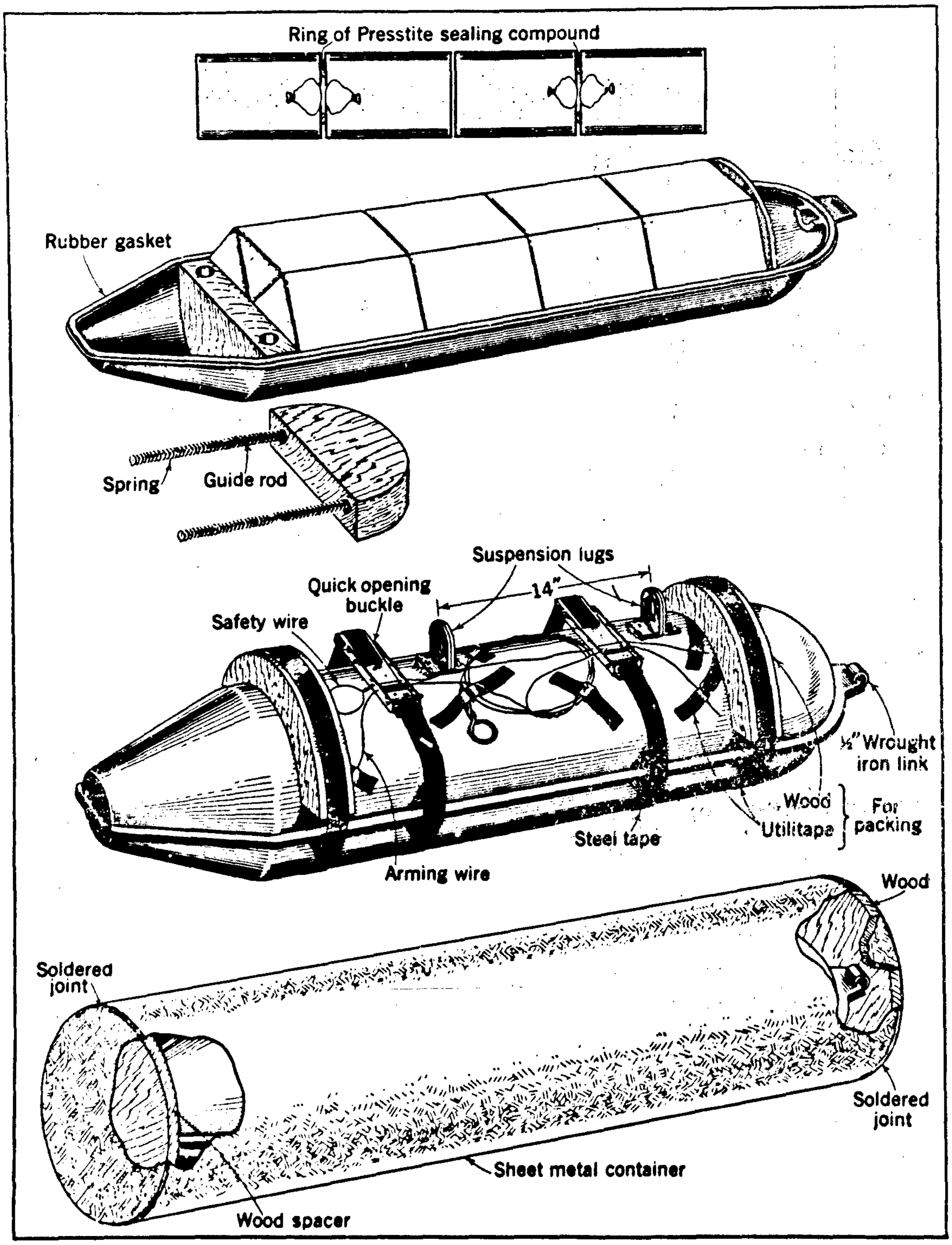

FIGURE 3. Quick-opening clusters of 21 City Slickers, Triangular.

packaging of a quick-opening cluster of 24 CST's are shown in Figure 3. These clusters were carefully tested several times at the U. S. Naval Proving Ground, Dahlgren, Virginia, and found to operate satisfactorily and safely. The two sections of the case were hinged securely together at the nose to prevent initial opening at that point when the bomb was released into the airstream. A pair of springs, compressed into wells drilled in blocks of wood mounted in the tail section, forced the sections apart at the tail, when withdrawal of the arming wire from the buckles allowed the steel straps to open. The 24 CST's were packed into the casing in pairs after removing their tear tabs and cementing the two units (with their ignition holes abutting) by Presstite Sealer. This temporary seal sufficiently waterproofed the units during their brief exposure to air while the bomb casing was being loaded.

On release from a torpedo bomber at altitudes of 150 to 600 ft and speeds of 175 to 300 knots, the clusters opened an average of 40 ft behind the plane and 25 ft below it, the individual CST's or pairs spread out in the airstream behind the plane and gave pattern areas roughly as shown in Table 1.

TABLE 1. Results of release of CST's from torpedo bomber.

Altitude of release	Diameter of pattern
600 ft	150 ft
450 ft	80 ft
175 ft	60 ft

CST's so released withstood the impact on water very well and functioning was well over 80 per cent with normal burning.

Another use for the CST that seemed even more attractive was as a munition of opportunity to be carried by aircraft operating over water. Release was by hand in a cluster of six units bound loosely together with tape, as illustrated in Figure 1. Just prior to release from the plane the rip cord could be pulled, tearing off all the tabs and readying the units for instant operation on contact with water. These clusters of six fell through the air as a unit, which on striking the water broke apart scattering the individual igniters over an oblong area. There was some skipping, with the units coming to final rest about 30 yd ahead of the point of original impact.

Probably the PR would be useful in a similar operation. As already stated it has the added features of delayed action (either on land or water) and of operation on land, features which might recommend it in some special operations. Needless to say, all types of oil slick igniters could be used by individual foot soldiers and thrown into slicks by hand, and, because of demonstrated reliability, a single unit or perhaps a pair should suffice for a given target.

2.9 PERFORMANCE

Earlier work [5] cast some doubt on the practicability of igniting bodies of floating oil, it being noted that ignition of films of less than 0.1-in. thickness was impossible. There was some question also whether crude and heavy oils such as Diesel and Bunker C, from which all volatiles had been stripped, could be ignited at all in large bodies. Also, it appeared that waves, wind, and passing ships could be expected to produce an oil-water emulsion which would not burn under any conditions.

These doubts were settled by many tests under a variety of temperature and wind conditions. It was thus definitely established that films over 0.1 in. in thickness could be reliably ignited by the extremely hot flame of the CST or PR. Because of the consistent performance of the igniters, the scattered pattern expected on jettisoning from a plane, and the size of the slicks encountered in the field, it seemed reasonable to assume their function from a single large-scale demonstration. This was arranged by officers assigned to OSS and took place on the New Jersey shore in June 1944 when 1,000 gal of Navy special fuel oil was ignited by the action of a single CST in less than 4 min.[6] The fire burned into the wind with flames billowing to a height of 50 ft and lasted for 7 min. As in all cases, there remained afterwards a considerable unburned tarry residue floating on the surface.

This large trial was of course preceded by many small trials and demonstrations performed by the contractor and the division's central laboratory.[7] In all these, as well as in the large trial, the units were thrown in by hand, and it was independently shown that their functioning was unimpaired when thrown from aircraft.[8]

Chapter 3

GRENADE, HAND, FRAGMENTATION, T-13 (BEANO)[1, 28]

3.1 INTRODUCTION

The work of Division 19 in the field of impact hand grenades had its origin in a request received from the Research and Development Division of OSS on th-- own behalf and with the support of the Grenade Section of the Ammunition Division of the Army Ordnance Department. As the development proceeded, contacts in the Army included the Army Ground Forces, and in the Navy, the Marine Forces, both of these groups being the branches using such a weapon. Upon withdrawal of the division from the problem in June 1945, the grenade became the exclusive charge of the Ordnance Department, which continued experimental and developmental work. No formal problem request was ever received from the Army or Navy in distinction to OSS.

The ideas underlying Beano [1,28] were not original: it had been frequently suggested previously by responsible individuals that first an improvement in the standard existing U. S. Army fragmentation grenade was needed; that, secondly, an impact type of grenade would be a desirable adjunct to the Army's munitions; and that, thirdly, a grenade based on the size and shape of a baseball would be better adapted to use by the average American soldier than was the heavy pineapple-shaped Mark II. The poor performance of the latter, which gave rise to that opinion, was later greatly improved by the substitution of 2.05 oz of cast TNT for the previously used filling of 0.74 oz of E.C. nitrocellulose powder.

A combination of the above three guiding principles led to the development of Beano, although various other requirements were included in the statement of the problem as well. These included specifications regarding sensitivity to impact, a dual arming system with the second arming operation occurring after the grenade left the thrower's hand, and the usual requirements of waterproofness, shock resistance and safety to the user. The fulfillment of all these points to the satisfaction of the Ordnance Department was not accomplished in the time available, but was very nearly achieved. Whether it was so nearly achieved during the active days of World War II as to have warranted field use is a matter of opinion. At least it can be said that Beano should be a valuable weapon in any future wars and a most useful adjunct to the now improved Mark II grenade which it complements in many respects.

3.1.1 Exact Requirements

The characteristics, suggested and implied, of this grenade were: (1) It should be the same size and shape as a baseball (a sphere 9½ in. in circumference). (2) It should approximate its weight. As shown in Section 3.2, this was eventually fixed at 11 ± 1 oz. (3) It should fire on impact rather than by time delay as did the Mark II, which employed a Bouchon fuze of approximately 4.5-sec delay. (4) It should fire reliably when dropped 18 in. onto sponge rubber. This measure of the sensitivity was later modified to a 12-in. drop equatorially onto concrete. (5) It should be spherically balanced, a requirement which was approximated in the first model of the fuze T-5 but more exactly met in the final model T-5E3. (6) It should have "optimum lethal fragmentation." Just what this meant was a matter of personal interpretation, since there is nc satisfactory criterion of lethality of particles which connects size, mass, and velocity with personal injury regardless of the part of the anatomy struck. Some discussion of this point will be found in Section 3.5.3. (7) It should have two arming mechanisms, the second to take place during flight. This seemingly difficult specification was met most satisfactorily by the so-called butterfly (see Section 3.4.3). (8) It should be waterproof, capable of withstanding the Army Ordnance Jolt and Jumble Test, and its safety and operation should be unaffected by rough handling and severe weathering.

3.2 DETERMINATION OF ALLOWABLE WEIGHT[3]

The original hope that Beano might not only have the same size as a baseball but also the same weight (5½ oz) was doomed at the outset by the required ratio of weight of high explosive filling to weight of case, which provided the lethal fragments. Either the explosive charge would have to be diminished and the case made of very light material or else the overall weight of the grenade wo-ld have to be significantly increased to over 5½ oz. The latter course was adopted and the specification (2) above was

established. The figure of 11 ± 1 oz was derived after several series of trials in which soldiers were provided with a variety of spheres, cubes, and cylinders of wood variously weighted and, in repeated throwing trials, judged for accuracy, range, and endurance. The original studies indicated that 12 oz would be the point of maximum efficiency,[3a] a decision which, by coincidence, just sufficed to cover the optimum weights of the fuze body, the fragmentation casing, and the explosive filling.

Later studies showed[3b] that the average obtainable range increased about 1 yd (out of approximately 45 yd) for each decrease of 1 oz in weight. See Table 1.

TABLE 1. Summary of throws for distance.

Weight	No. throws	Arithmetic means of distances
12 oz	309	47.5 yd
14 oz	309	45.1 yd
16 oz	309	43.5 yd
18 oz	309	42.4 yd

The information on accuracy was more difficult to analyze and only led to the generalization that, barring fatigue and figuring the accuracy of each throw as the maximum distance readily attained with a given weight, there appeared to be no significant change in accuracy with change in weight. All throws were made overhand in contrast to the side and underhand technique usually employed with the 22-oz Mark II.

3.3 SELECTION OF CASE[7]

Extensive trials of a number of metals including steel of several thicknesses, aluminum, and magnesium showed at once that, if anything more than a blast effect were desired of Beano, a steel case was definitely needed.[5] This was true regardless of the type of explosive filling employed.

Table 2 shows very clearly the preference for steel to aluminum (a similar table for magnesium could be presented) and at the same time indicates the value of a filling more dense than TNT at 0.80. A slight preference would also seem to be indicated for a longitudinal rather than an equatorial weld. This was not sufficiently clear, however, to warrant the additional complication entailed in manufacture.

A choice of case thickness was made in favor of 0.040-in. steel because of greater ease in manufacture and because of the greater density of fragments, which were admittedly lighter and of shorter range.

TABLE 2. Summary of fragmentation studies of experimental spherical grenade cases.

Case and Weld	Wall thickness inches	Charge	Density	Results 46½" belt of 1" pine at 85" No. throws per sq ft
Steel Equatorial	0.040	TNT	0.80	0.686
Steel Longitudinal	0.040	TNT	0.80	0.850
Steel Equatorial	0.060	TNT	0.80	0.622
Steel Equatorial	0.040	Cast Pentolite	1.62	1.14
Aluminum Equatorial	0.095	TNT	0.80	0.262
Aluminum Equatorial	0.135	TNT	0.80	0.262

It is convenient to express the performance characteristics of a Beano by giving the range at which the density of perforating particles averages 0.35 per sq ft,[a] the average linear dimension of the holes perforated, and the average weight of the perforating fragments. These data are given for the two weights of steel cases in Table 3 and show a slight preference for the 0.040-in. case which was used in all production models.

TABLE 3. Performance characteristics of Beano.

	HE charge-case ratio	Range to d-35	Average dimension	Average weight
0.040 Steel	1.07	10.0 ft	0.31"	0.30 g
0.060 Steel	0.59	7.8	0.45	0.56

(Similar data could be included which would indicate that the fuze assembly used in conjunction with this case would give better fragmentation, if made of aluminum rather than the bakelite actually employed in all but the T-5E2 and T-5E3 production.[7])

Selection of the proper filling of high explosive for this case narrowed to a choice between TNT and RDX (Composition A) after the exclusion of ammonium picrate and cast pentolite. The choice between the two remaining explosives was finally made by the Services in favor of the latter on the basis of evidence such as that shown[11] in Table 4. Although the total area of penetration was about the same in all these cases, the number of particles was much

[a] When the fragment density is 0.35 or greater, a man, on the average, will be struck in other than a trivial region by one or more fragments.[7]

larger in the case of Composition A (although the average weight of each was correspondingly smaller), and Composition A was preferred.

TABLE 4. Comparison of TNT & Composition A fillings.

Charge	Density	Booster	No. throws*
TNT	0.8	2.34 g tetryl	106
TNT + beeswax	0.87 + 7% beeswax	2.34 g tetryl	56
TNT	0.87	8 g tetryl	117
Composition A	0.93	2.34 g tetryl	281

* (Cf. Table 2)

The case in final form may now be described as consisting of two stampings of 0.040-in. steel, copper brazed at the equator. One stamping had an opening to receive the fuze and was provided with the brazed threaded insert holding the aluminum former cup. Filling was by either Composition A with a density of 0.93, which gave a total weight to the grenade of 11.9 oz, or by granular TNT with a density of 0.8, which gave a total weight to the grenade of 11.3 oz. The volume available for high explosive filling was 140 cc, and this allowed the use of 4.6 oz of Composition A or 4.0 oz of TNT. The outside diameter of the case was $2\frac{7}{8}$ in. at the equator. The weight of the empty case assembly, including the aluminum former cup and its brass retaining ring was 4.8 oz.

3.4 DEVELOPMENT OF THE FUZE T-5[15]

3.4.1 Origin of Design

The division was indebted primarily to the British for several design features of the impact fuze. This was because of the large scale production for the British Army, both in the United Kingdom and in Canada, of their standard grenade No. 69 Mk. 1 which was equipped with an impact type bakelite fuze. British reports and suggestions[2,4] used by Division 19 research workers gave valuable assistance, especially in locating pitfalls to be avoided. The fuze T-5 which finally resulted is shown in cross section in Figure 1.

A comparison of the T-5 with British fuze shows a difference. The secondary arming pin, attached by nylon string to the butterfly cap, in the American design entered the firing pin mount vertically and gave safety by holding apart two small steel balls, which engaged the shoulder of the primer mount. In the British fuze No. 247 this pin entered at an angle,

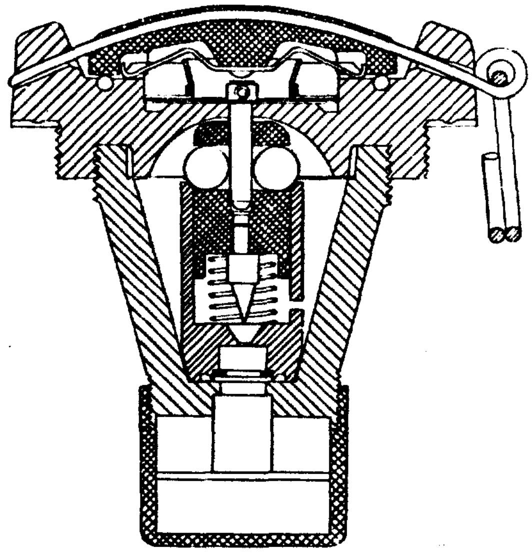

FIGURE 1. Cross section of T-5 fuze.

there were no balls, and it was possible to throw the grenade in such a way that arming in flight could not occur. Another significant change was in the elimination in the T-5 of one of the conical surfaces on which the inertia parts of the fuze moved at the moment of impact. This insured a better alignment of the primer and the detonator at the moment of firing.[15a]

3.4.2 Assembly and Description

Figure 2 shows the T-13 grenade with its case and T-5 fuze disassembled. The fuze itself was composed of a number of metal and two bakelite parts, the fuze head and the fuze body. The fuze head was equipped with threads to screw into the grenade and to receive the fuze body. On one side it was provided with a smooth cam surface with a central opening through which passed the secondary arming pin. On the other side it was provided with a brass-inserted spool around which a Nylon thread was wound connecting the secondary arming pin with an aluminum butterfly cap, which up to the moment of use was held in place by the arming pin (a ring-pulled type supported by two ears provided in the bakelite casting). The body of the fuze was roughly conical in shape and had a flat inner surface on which the fuze parts rested. This was penetrated by a hole, which in assembly received the detonator. The bottom end of the bakelite part was threaded to accommodate an aluminum cup, which in assembly contained a felt

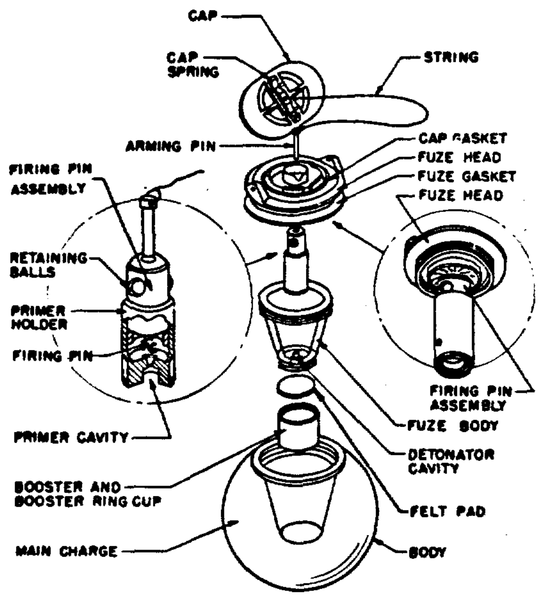

FIGURE 2. Disassembled view of T-13 grenade and T-5 fuze.

pad and two tetryl pellets constituting the burster insuring high order detonation. The metal fuze parts which operated inside the bakelite housing consisted of a brass primer mount and a brass plunger. The primer mount, which rested upon the flat inner bottom surface of the fuze body, was provided with a cavity, in which the primer was mounted. A steel firing pin was an integral part of the heavy brass plunger which moved smoothly inside the primer mount without actual contact between the firing pin and the exposed primer because of a weak creep spring.

The butterfly was cast aluminum with cross ribbing to provide a good finger grip. It was connected to the secondary safety pin by 6 in. of 30-lb nylon line. The radius of the dome or cam and its position relative to the fuze body were dimensionally important. On the basis of British work this interior angle was as close to 115 degrees as possible. The strength of the creep spring was an adjustable feature which determined the sensitivity of the grenade; it consisted of 6 coils of 0.010-in. diam tinned music wire with open-end winding. The sharpness and angle of the firing pin was also vital; it was necessary that the angle be less than 0.010-in. flat.[6]

The initiating system[15a] consisted of the M26 primer, the M17 detonator, and a tetryl burster. This train was selected because it represented the maximum sensitivity obtainable in standard items. The M26 primer was the suggestion of Picatinny Arsenal. It contained 2.05 grains of 40-35-25 mercury fulminate — potassium chlorate — antimony sulfide pressed at 20,000 lb per sq in. The charge was contained in a gilded metal cup covered with an 0.0012-in. gilding metal disk sealed with waterproof wax. The primer was of the stab type. The detonator, also recommended by Picatinny Arsenal, was the M17 and contained a primary charge of 3.86 grains of lead azide pressed at 10,000 lb per sq in. and a booster charge of approximately 1.27 grains of tetryl containing a maximum of 2 per cent graphite. The burster consisted of two pellets of tetryl roughly ¾ in. by ¼ in. with a density of 1.49. Their total weight was 5 g, which was approximately twice the minimum. This assured satisfactory performance regardless of the explosive used in the case.

3.1.3 Arming and Operation

In the unarmed condition the grenade was rendered safe by the intrusion, into the upper part of the firing pin mount, of the secondary safety pin, which penetrated the bakelite cam surface centrally. While this safety pin was in position in the firing pin mount, it held apart two steel balls which protruded beyond the edge of the primer mount and effectively kept the fuze parts from movement. Upon the withdrawal of the secondary arming pin, the steel balls no longer performed this function and the brass fuze parts were free to move within the bakelite fuze body. Any substantial deceleration of the grenade in this condition, regardless of direction, resulted in movement of the firing pin mount, within the primer mount, against the creep spring with resultant piercing of the primer, passage of the resulting spit into the detonator, and thus in explosion of the grenade.

When the grenade was thrown after removal of the safety pin, the cap was forced away from the fuze body by a cap spring and acted as a parachute, unwinding the nylon string and pulling out the arming pin while the grenade was in flight. With an average throw, arming occurred at a distance of about 20 ft.

3.5 PERFORMANCE

3.5.1 Sensitivity

Probably the most significant quality of any impact fuze is its sensitivity. In the present case it was desired that a fuze be made which would fire reliably

on striking any solid surface with the force ordinarily supplied by an average thrower or by gravity from a reasonable height. This indicated a fuze of considerable sensitivity, and, at the same time it was clear that the fuze should not be so sensitive as to be an unusual hazard in assembly or in correct usage. The exact requirement finally framed [see (4) under Section 3.1.1] was meant to represent the best compromise between these opposite demands. It will be seen at once that it did not correspond to the extremely variable field conditions certain to be encountered.

The most valuable data on the subject was acquired by the Army Ground Forces in exhaustive tests conducted by the Infantry Board at Fort Benning, Georgia.[21] Using live, as well as dummy, grenades and Army personnel, these tests made it clear that the percentage of malfunctioning caused by differences in targets was greatly affected by the technique used in throwing. Flat trajectories resulting in a glancing impact produced a relatively high percentage of malfunctions which increased rapidly with the softness and resiliency of the impact area. On targets of the latter type a high, arched trajectory was found essential to give reliable performance and even so, in exceptionally soft mud, water, or freshly fallen snow,[23] duds averaging 9 per cent could not be avoided. This defect had to be accepted as inherent in the design and represented a danger in the use of Beano by troops operating offensively under such terrain conditions. Presumably, the perfect impact grenade would be equipped with a secondary time delay firing system which would dispose of these duds after an interval of several seconds. Such a design was at times discussed but, in the time allotted, could not feasibly be developed.

3.5.2 Fragmentation

Many independent fragmentation tests were conducted by NDRC,[1,11,12] Army Ground Forces and chiefly by the Ordnance Department [22] at Aberdeen [9] and Picatinny,[11] with generally good agreement. The standard Ordnance test procedure was employed, in which the total number of perforations was counted in two facing semicircles of 1 in. No. 2 sugar pine of 10 to 20 ft diameter and 6 ft height.[9] When the grenade was fired in horizontal position, the fuze axis was in line with the common diameter of the targets and at mid height. Panel perforations were accepted as the significant criterion.

Table 5 presents some interesting data of this type.[8,22,24]

The figures in Table 5 indicate the continued improvement in the functioning of the Mark II grenade as the fuze and filling were altered. They indicate also that Beano was closer to an offensive type grenade, since stray particles did not fly to great distances, and that Beano's efficiency at close range was nearly twice that of the standard grenade — a feature which is important when it is realized that Beano could be more accurately thrown over all ranges because of its smaller weight (11.5 oz vs 21 oz) and more convenient size and shape.

TABLE 5.

Horizontal position			Average number perforations for semicircles			
Type	Load	Fuze	10′	20′	40′	80′
Mk II	0.74 oz E.C.	M10A2	5	2.2		
Mk II	0.74 oz E.C.	M6A3E1	19	9.5		
Mk II	2.05 oz TNT	M6A3E1	25.5	16.0	9.6	2.0
T-13	4.0 oz TNT	T-5	22.8	6.0		
T-13	4.6 oz Comp. A	T-5	50.2	12.0	1.2	0.0

The velocity of the Beano fragments averaged 4,100 with TNT loading and 4,900 ft per sec with Composition A filling.[9]

A table similar to Table 5 with the grenades placed vertically would show the difference in performance between the last Mark II type and Beano to be small and slightly in favor of the Mark II at the closer ranges. The two were therefore comparable in fragmentation at 10 and 20 ft, but beyond that the Beano fragments very quickly lost their momentum, thus making the grenade safer to the user with less need for protection.

3.5.3 Lethality

Since this was the object of developing the grenade, some judgment must be given on the performance of Beano on this score, even while it is realized that an exact criterion is not possible. Excellent attempts of this type have been made however, of which two appear most significant.[19] From these it would seem that the perforation measurement used in Table 5 may not be a true appraisal of lethality or incapacitation. The tremendous number of particles, many of which are very small (about 0.0025 oz), flying at these very high velocities can be counted on to deliver the maximum casualty producing hits per unit area, the closer the target is to the exploding gre-

nade. These interpretations reinforce those given in the preceding section that Beano would find its chief usefulness as an offensive grenade. At the same time, analysis of the data already presented would tend to show that, at the range of 20 yd, all types of Mark II and Beano are approximately equivalent, with Beano more effective at shorter ranges, and the Mark II at longer ones.

The whole argument presented may be upset by the entirely unpredictable effect of clothing, which in quantity and location is an uncontrollable variable affecting the results obtained from all grenades.[13] Just what this effect would be in a given shot would be impossible to say, but it seems safe to predict that clothing would more seriously affect the smaller particles of Beano than the larger and more massive ones emitted by the Mark II.

3.6 PRODUCTION [1]

Although in principle the Beano fuze appears simple, its manufacture in tremendous quantities was attended by more than the usual quality control difficulties. These were centered almost entirely in the T-5 fuze and its successors, each of which was introduced to correct some fault in the preceding design. The final fuze made during NDRC participation, the T5E3, came close to meeting all the previous objections and proved easier to manufacture. As an assistance to the manufacturer and a guide in maintaining the quality in full production which had proved adequate in the semiproduction, Tentative Acceptance Requirements [20] were drawn. These were based on Ordnance results in the rough-handling, weathering, and Jolt and Jumble tests,[10] the behavior on long storage,[14] exposure to tropical organisms,[16] and similar information. Even so, the original requirements were altered on several occasions by common consent, and, before the final closing of the assembly lines (after V-J day), a variety of special tests and more conventional production control tests had been standardized and had proved their worth.[1]

These tests were primarily concerned with safety of the fully assembled grenade and the partially armed grenade on accidental dropping and on throwing. Other features of course were tested, such as waterproofness and reliability of function. The results of many thousands of tests of this type will be found in the final report of the contractor.[1]

The safe packaging of the loaded grenades for delivery to the field offered difficulties which were, however, fully met by the Ordnance development of a satisfactory container and the adoption of the practice of shipping the fuzes and the bodies disassembled from each other to avoid simultaneous detonation of a whole box upon the accidental firing of a single grenade.[17]

3.7 MODIFICATION OF THE FUZE T-5

3.7.1 Need for Improvement

Although several thousand Beanos had been produced and tested by NDRC without a single mishap, the early Ordnance production, in an unexplained accident, caused a fatality in testing personnel at Aberdeen.[22] At once the fuze design was reopened and two modifications were forthcoming, the T5E1 and the T5E2. The latter represented a significant improvement in the safety of the fuze and differed from the T-5 and T5E1 in that the steel balls in the firing pin mount were omitted and that the brass piece was slotted to receive a steel key, the shoulder of which, resting on the primer mount, rendered the grenade safe when the arming pin was in place. Removal of that pin, however, allowed the key to slip into the firing pin mount and to position its sharpened tip directly over the primer cap which it pierced when the fuze functioned. The details are shown in Figure 3.

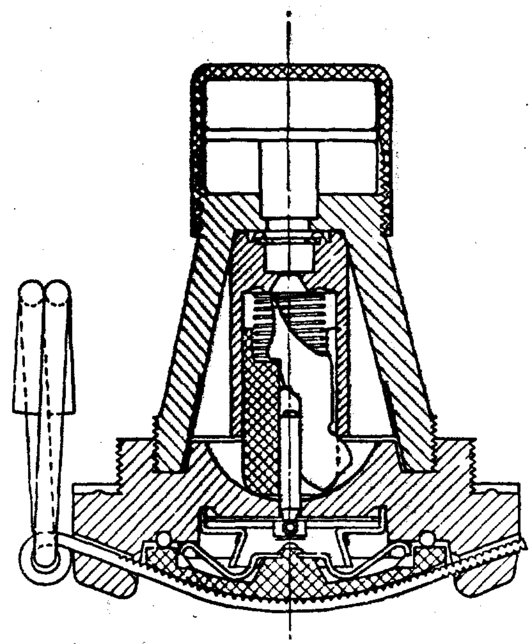

FIGURE 3. Fuze, grenade, hand—T-5E2.

With the firing pin a part of the key, it was impossible to have a premature firing because of faulty or incomplete assembly of parts, a serious defect in the T-5 fuze which, it was supposed, might have caused prematures, and did require their reworking.[23]

After satisfactory tests of the new design [26] but before the T5E2 was released, further accidents with the T-5 occurred in the field. These were never completely explained. They resulted from the developmental point of view in a further improved grenade in which the case was slightly altered in dimensions (T13E1) to permit the fuze to seat itself more deeply in the body, thus eliminating its bulgy appearance and correcting a slight non-coincidence in the center of gravities of the fuze parts and the grenade. It was supposed that by centrifugal force this could result in premature firing near the thrower's hand. It was indeed demonstrated[1] that at 1,800 rpm a T-5 fuze would fire from this cause, but nc thrower in actual tests was ever able to hurl a Beano with more than 1,200 rpm.

At the same time, the nylon thread connecting the butterfly with the arming pin was shortened to prevent the butterfly from striking the spinning grenade

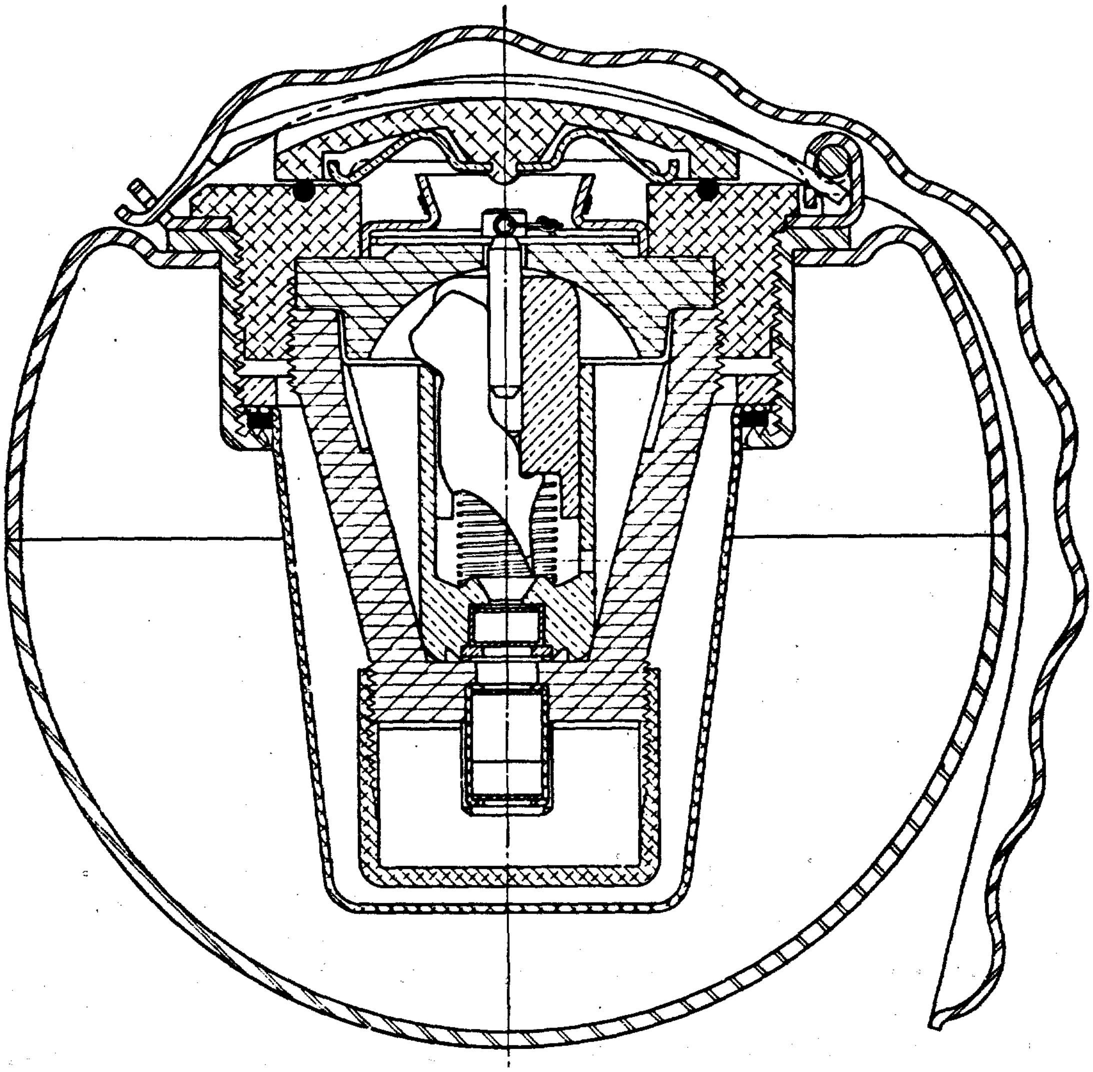

FIGURE 4. Fuze, grenade, hand—T-5E3 in T-13E1 case.

in mid air when the pin was withdrawn, thus conceivably giving sufficient lateral movement to fire the fuze — a happening which was never demonstrated to occur.[1]

The T5E3 fuze was also supplied with a long bouchon-type level handle so that the user would have his hand over the butterfly when he threw the grenade. This point was corrected after the Ordnance at Aberdeen discovered that the Beano could be consistently prematured in the thrower's hand if, contrary to the instructions, he did not retain his hold over this part.[24]

The details of the final design with these modifications are seen in Figure 4 of the T13E1 grenade with the T5E3 fuze.

3.8 MODIFICATIONS OF BEANO

3.8.1 White Phosphorus Loading

White phosphorus loading is discussed in Chapter 4 of Part I of this volume.

3.8.2 Concussion Loading [27]

At the suggestion of officers in Army Ground Forces, a preliminary study was made of the performance of Beano bodies filled with flash powders developed by Section 11.2 of NDRC. It was believed that the concussion blast might be effective, without accompanying shrapnel at close range, and that at night the intense flash would blind the enemy for a crucial period of many seconds. The cursory tests performed indicated that the idea was well-based, but, because of the termination of hostilities, it was never fully developed. It appeared that one of the aluminum cases used in the WP Beano (Chapter 4) when filled with a composition of 200-mesh potassium perchlorate (60.0 per cent) and PXS-885 50-50 aluminum potassium alloy (40.0 per cent) gave the best results. The filling had a total weight of 160 g and was dispersed and detonated by the standard Beano fuze in which the usual tetryl bursting charge was replaced by one of 2.5 g of black powder.

3.8.3 Time Delay Fuze [19]

Although the impact fuze of Beano was its chief novelty, officers in Army Ground Forces believed that the grenade would have greater general usefulness, if it could be supplied on occasion with a time delay fuze which would be interchangeable in the Beano case with the impact fuze. Two models based on both the T5 and the T5E2 fuze designs were produced in very limited quantity. In each case, the secondary arming pin was integral with the butterfly, and, when the grenade left the hand of the thrower, the butterfly and the arming pin were ejected by a strong underlying spring, with the result that the firing pin, which was also under spring tension, stabbed an initiating system and began a pyrotechnic delay. This delay column was ⅞ in. in length and provided an elapsed time of approximately 4½ sec. It consisted of a primer of 70-20-10 antimony sulfide — lead thiocyanate — potassium chlorate, a delay powder of 85-15 barium oxide — selenium with added talc, and a standard detonator of lead azide.

3.9 CONCLUSION

The division personnel regret that a spherical impact grenade, fulfilling the requirements of safety and effectiveness determined by the Ordnance Department, was not produced to meet the large needs of the Ground Forces. It is hoped that its work, however, will stimulate future developers to successful production of a weapon of this type which will undoubtedly be a valuable complement to the standard improved Mark II grenade.

Chapter 4

WP BEANO (OD-176)

4.1 INTRODUCTION

It was the desire of liaison officers in the Army Ground Forces that several modifications of the original Beano be developed for production and use following the hoped-for adoption of the impact, fragmentation hand grenade as a general weapon. Two of these, the Concussion Beano and the Time Delay Beano, have already been mentioned. A third, a modification in which the loading was white phosphorus (WP), is described in this chapter. The development was requested by the Ordnance Department (OD-176) and closely followed by OD and the Chemical Warfare Service, without whose interest and assistance an entirely satisfactory solution would not have been forthcoming.

It was decided, as a working hypothesis, that the WP Beano (*grenade, hand, smoke, WP T-28* and its accompanying fuze T-21) should have the same dimensions and weight as the standard high explosive grenade T-13 and should use so far as possible the same fuze T-5, altered only in those details imposed by the new requirements. A decision, similar to the one made in the case of Beano, was required, in which a compromise was made between the danger and the effectiveness of dispersion.[9,11] Ultimately a compromise was made between the antipersonnel features of WP and the economical and efficient utilization of the volume and weight of WP available within the space of a Beano casing. A bursting charge of tetryl would eject particles of WP, ¼ to ½ in. in diameter, these being judged sufficient to incapacitate and yet sufficiently numerous to strike a target at ranges up to 20 yd.

The result of these considerations was the complete development and semi-production of a grenade, which appeared satisfactory in limited NDRC testing but which was never completely tested by service boards because of design troubles with the T-5 fuze (see Section 3.7). At the time when the division terminated its activity, however, it had shown that aluminum was suitable for a body case, that it was compatible with WP, that its strength and lightness made it practically unique as a satisfactory material, and that WP was superior to similar fillings (PWP and SWP) for such use.

4.2 THE CASE T-28[2]

4.2.1 Unsuccessful Attempts

Cases made from steel, brass, copper, ethylcellulose, and aluminum were tested. Of these, only aluminum cases proved satisfactory, but the others deserve some mention. The case construction of the T-13 (Section 3.3.3) naturally suggested steel, which was ordinarily used in WP munitions, but which for two reasons seemed unsuitable here. First, there was the rigid requirement that no leakage should appear at temperatures from −50 to +150 F even after rough handling, and, secondly, there was an unfavorable weight relationship which would not permit a large enough charge of WP to be useful. In regard to leakage, it must be remembered that only a thin gauge metal, an involved form difficult to seal, was possible; the overall weight of the WP grenade was held the same as the high explosive (11 ± 1 oz), while the density of the filling had increased from 0.93 to 1.82.

Using the standard case design with the T-13, but changing the steel thickness to 0.020 in., the lowest feasible point, and providing a seal of Dewey and Almy No. 200 can-sealing compound between the underside of the lip of the aluminum former cup and the inner edge of the steel hemisphere, a case was obtained which survived moderately rough treatment, but not prolonged storage.[5] This basic design is illustrated in Figure 1.

The standard Beano case of 0.040-in. steel of this design was so heavy that the payload was too small, and, furthermore, the tetryl burster charge required to open this heavy case was so large that it completely shattered the small WP charge and produced only harmless smoke. The 0.020-in. steel case, while without this defect, fragmented unevenly, yielded first at the hemispherical welded seam, exerting a marked and unpredictable directional effect on the burst, and failed to eject the full WP load. Similar results were obtained with identical brass and copper designs, and it appeared that a uniform case of weaker and lighter composition was necessary.

Two attempts using blown ethylcellulose[3] and aluminum (0.036 in. 2S alloy), both of the same

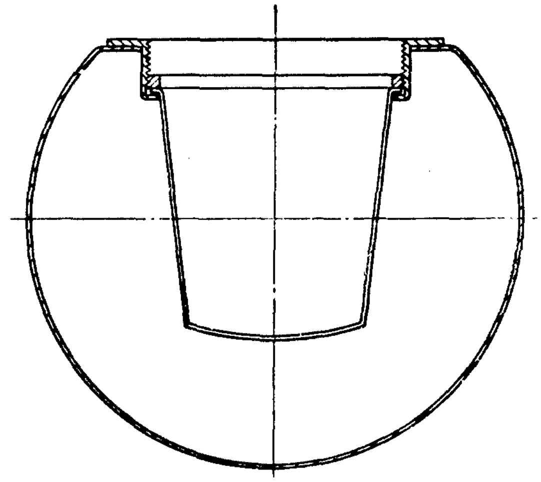

FIGURE 1. 0.020 steel WP Beano case.

design shown in Figure 1, showed conclusively that a step forward had been taken. More uniform distribution of WP particles resulted, and a significantly improved payload was obtained. Nevertheless, the inherent weakness of the design was apparent, because leakage and uneven fragmentation of the case still occurred. A second design was therefore indicated and experimental sample orders of the type shown in Figure 2 were tested in the most promising materials, ethylcellulose and aluminum. The latter is shown in cross section. Like the units shown in Figure 1, these cases required a much smaller bursting charge of tetryl than the standard T-13, gave more uniform performance and improved efficiency, and corrected the weaknesses of the earlier design.

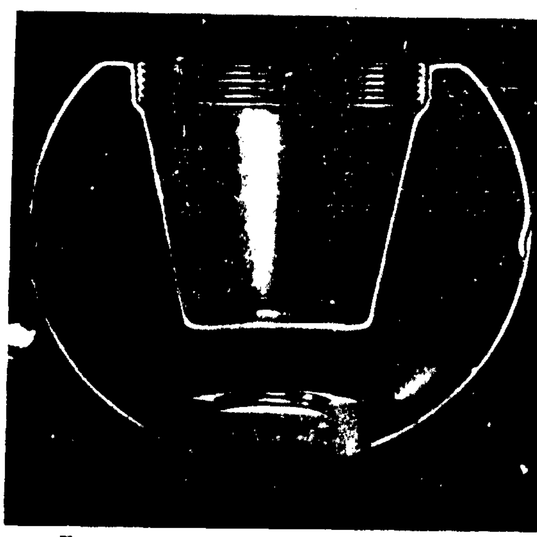

FIGURE 2. 0.036 aluminum WP Beano case.

A choice between ethylcellulose and aluminum was not difficult to make, for the former was shown conclusively to be incapable of surviving the rigorous Jolt and Jumble Test of Army Ordnance as well as the weathering and surveillance tests required by CWS. In addition, the plastic unit was combustible, a most undesirable feature in a container of a spontaneously combustible material such as WP. Therefore an aluminum body of the design shown in Figure 2,[9] was chosen.

Table 1 gives the pertinent data for these various models.

1.2.2 The Final Design

The production body was made of five parts, all aluminum: two stampings, a fuze ring, a filler bushing, and a sealing plug. The stamping, which incorporated the fuze former cup, was the result of very excellent technique on the part of the semi-producer.[12] The hemispherical stamping, which carried the filling port, was more conventional. Both were made from Alcoa No. 21 brazing sheet (heat treatable and 0.032 in. thick). The alloy consisted of base metal aluminum, coated thinly on one side with an alloy of low melting point. The unit was assembled in a brazing furnace where all joints were formed simultaneously with the aid of proper fluxing. The two stampings assembled in one operation the final unit case, a ball, bearing the filler bushing and fuze ring. No difficulty was encountered in producing uniform and tight joints, except in the sealing plug, which screwed into the female bushing. Here there was some indication that in the brazing process the threads of this bushing were distorted and no longer met the original rigid specifications. It seems likely that, if large-scale production should be undertaken, it would be advisable to cut these threads after the brazing operation.

Filling of the unit (see Section 4.4) was accomplished through the ⅜-in. bushing and, in the case of WP, by the use of an automatic dry-loading machine operated at Edgewood Arsenal. Closure was accomplished by an air torque wrench exerting 200 in-lb pressure on a ½-in. long plug. With the high torque quoted, it was found necessary to use a thicker female bushing than originally designed.

The compatibility of aluminum and various alloys was demonstrated by data supplied by Edgewood

TABLE 1. Weight and filling relationships for various WP Beano cases.

	A	B	C	D	E	F	G	H
Weight, ounces								
Case	4.52	2.38	4.960	5.45	1.586	1.37	....	1.191
Cup	0.488	0.488	0.626	0.608	0.193	0.193	....	0.154
Ring	0.112	0.112	0.208	0.208	0.208	0.208	....	0.112
Top	....	....	....	....	....	....	1.171	....
Bottom	....	....	....	....	....	....	0.490	....
Plug	....	....	....	....	....	....	0.015	....
Total	5.120	2.980	5.794	6.266	1.987	1.771	1.676	1.457
Fuze	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Complete unit (less filling)	7.62	5.48	8.29	8.76	4.48	4.271	4.17	3.96
Wt of filling which will give a total unit wt of 12 oz	4.38	6.52	3.71	3.24	7.52	7.73	7.83	8.04
Wt of WP if 10% void allowed	8.0	8.0	8.0	8.0	8.0	....	8.0	8.0
Per cent of total possible with total unit wt of 12 oz	54.8	81.4	46.3	40.5	94.0	....	97.8	100.0

A Standard HE Beano case made from 0.040 steel with short-style* steel cup and brass hold-down ring. Filling vol 140 cc.
B HE Beano style case made from 0.020 steel with short-style steel cup and brass hold-down ring. Filling vol 140 cc.
C HE Beano style case made from 0.040 brass with short-style brass cup and brass hold-down ring. Filling vol 140 cc.
D HE Beano style case made from 0.040 copper with short-style copper cup and brass hold-down ring. Filling vol 140 cc.
E HE Beano style case made from 0.036 2S aluminum with short-style aluminum cup and brass hold-down ring. Filling vol 140 cc.
F HE Beano style case made from 0.032 No. 21 brazing sheet with short-style aluminum cup and brass hold-down ring. This unit was made 3" OD rather than the 2$\frac{7}{8}$" used on the other metal units. Over size.
G Northern Industrial Chemical Co. Ethocel unit. Outside diameter 2$\frac{11}{16}$" (Figure 2).
H HE Beano style Plax Corporation Ethocel unit with short-style Ethocel cup and brass hold-down ring. Filling vol 140 cc.

* Short-style cup. In the WP Beano, because of the reduced tetryl charge, it has been possible to reduce the length of the former cup by ¼ inch as compared to the cup used in the HE Beano unit.

Arsenal [8] where it was reported that on continuous immersion at atmospheric temperature, aluminum in WP showed no penetration greater than 0.008 in. per 100 months and this occurred almost entirely within the first 168 hours. The same conclusion was drawn by independent testers who employed temperatures up to 100 C with both dry and wet WP.[13] Under the same conditions, steel was considerably more susceptible to attack.

Table 2 summarizes the characteristics of the production model (Figure 2).

1.3 THE FUZE T-21

The only changes in the T-5 fuze necessitated by the new case and filling of WP Beano were in the size of the bursting charge of tetryl, the small aluminum cup which held the burster, and the length of the former cup which accommodated the fuze. With the case described above, data such as that given in Table 3 indicated that the burster charge of tetryl could be reduced to nearly one-half that used in the high explosive Beano while providing the apparent optimum compromise between WP fragmentation and the area of particle distribution. In the final fuze, the burster charge was set at 1.30 g. With the resultant saving in space, it was possible to reduce the length of the former cup volume required by the T-5 fuze and thus to increase further the payload of the grenade.

TABLE 2. Characteristics of production Model WP Beano case.

Material of construction	No. 21 aluminum brazing sheet XJ51S aluminum alloy for machine parts
Wall thickness of case, inch	0.032
Weight in ounces:	
Fuze less tetryl	2.62
Empty case	1.94
Tetryl	0.05
Total empty unit	4.61
Allowable for filled unit	12.00
Allowable for WP	7.39
WP to be put in unit	7.22
Volumes in cubic centimeters:	
7.22 oz of WP	117.5
Total available for filling	131.0
Voids	13.5
Void volume as % of total volume	10.5
Efficiency of loading	97.8%

TABLE 3. Number of hits of WP ¼ and ½ in. on 90-degree vertical target.*

Tetryl charge	5 yd	10 yd	15 yd	20 yd
0.75	36	45	12	9
1.00	625	35	7	2
1.25	797	31	5	4
1.50	443	88	..	..
2.00	189	29	0	3

* (Orientation: Fuze up)

4.4 THE FILLING

4.4.1 Alternatives

In addition to WP itself, fillings of a modified nature were considered. Chief among these were PWP (WP plasticized with a gel of xylene and GRS rubber [4, 7, 10]) and SWP (WP reinforced with steel wool).[11] Other attempts to alter the filling by the addition of rock wool, glass wool, cotton, and so forth, were given only cursory trials.

In brief, the dispersion and antipersonnel behavior of PWP and SWP were consistent but different from WP. The tendency in both PWP and SWP was to produce fewer and larger particles of the burning filling and to throw these a greater distance. Typical data giving the optimum performance of all three fillings are presented in Table 4. It should be noted that the different fillings require different burster charges for optimum performance.

TABLE 4. Number of hits of WP ¼ and ½ in. on vertical 90-degree targets.

Filling	Tetryl charge	5 yd	10 yd	15 yd	20 yd
WP	1.25	797	31	5	4
PWP	1.50	80	7	0	3
SWP	2.00	463	17	9	8

In view of the original requirements for maximum effect in the area closest to the point of burst, neither PWP nor SWP was given further attention. The work was abandoned, with the approval of the various Services, because only WP was, at the time, a standardized filling, and because there was no definite proof that PWP and SWP were equal to WP in antipersonnel behavior on a volume basis.

4.4.2 WP Filling

The decision as to whether WP should be loaded in this munition dry or wet was made by the Chemical Warfare Service. In the experimental loadings made at Edgewood Arsenal, an automatic dry-loading technique gave most satisfactory results. The inverted body received a delivery vacuum tube through the bushing hole, and loading was made to the lower edge of the bushing. The resulting void of about 10 per cent in the filled grenade [6] was a desirable feature, in view of the extreme expansion coefficient of WP. Closure was made, as already described in Section 4.2.2, with the assistance of a standard luting compound (Federal Specification II-W-261a), consisting of a mixture of 16 per cent linseed oil and 84 per cent basic lead sulfate. These procedures coupled with the use of a pipe plug, meeting the Army-Navy Aeronautical Specification AN-GGG-P-363, gave lots with less than 1 per cent leakage, thus comparing favorably with the results from standard munitions. Because of low surface tension, WP has always been a difficult material to seal.

4.5 SURVEILLANCE [5]

The seals for the production units were tested primarily in two ways, first, by static storage at −30 to 150 F with the plug closure down, and, secondly, by the Army Ordnance Jolt and Jumble Test. The former was by far the more severe and was ultimately met by the use of the methods given in Section 4.4.2.

4.6 PERFORMANCE [1]

Qualitative evaluation of the burst was possible with visual observation but a more accurate appraisal was obtained by using semi-circular targets grouped in 90-degree arcs around a center point at which the grenade was detonated. These targets consisted of individual manikins mounted upright. The number of splashes of WP greater than ¼ or ½ in. was counted after each shot. An accurate estimate of effectiveness required counting the number of similar hits on the enclosed area, hence a wooden floor was provided within the 10-yd circumference. Because of the slow velocity of WP gobs, those which fly upward and fall in lobs of high arcs may still be classified as effective, in contrast to similar particles of a high explosive grenade which would be valueless. So that there might be no ambiguity in these tests, the grenades were detonated by the impact of the T-21 fuzes when they fell from a specially designed dropping-tripod, which was operated by remote control.

Representative data of the burst pattern of the production model showed that, for most orientations

of the grenade, the coverage at 5 or 10 yd was uniform. Only when the filler bushing was pointing at the target was the coverage seriously less. This is perhaps accounted for by the behavior of the filler bushing and plug which were expelled as a unit on detonation. Also, a large amount of the WP filling tended to be thrown through the fuze opening. In terms of hits per unit area, the average for a 5-yd arc was 6.5 hits per sq ft, while for a 10-yd arc the average was 0.42 hits per sq ft. It is thus seen that the density for a vertical target at 5 yd was over 15 times that at 10 yd and that the frontal area of a man would receive 47 hits at 5 yd and 3 at 10 yd. These figures may be compared with 3.5 and 0.24 hits to be expected from the Mark 15 standard WP smoke grenade, and 1.2 and 0.01 hits from the British No. 77 grenade. This comparison is even more favorable when the three are adjusted by calculation to the same weight basis (see Table 5). The purpose of

TABLE 5. Average hits per sq ft of vertical target area per 7 oz of WP.

Grenade	5 yd	10 yd
WP Beano	6.5	0.42
CWSM15	1.75	0.12
British No. 77	1.05	0.01

these last two grenades, it should be noted, was primarily to make smoke.

A study of the area patterns indicated a tendency to a high density of hits in the direction in which the fuze was pointing and a rapid drop in density beyond 6 ft from the point of burst. The material which was lobbed into the air seemed to produce a band of increased density 15 ft from the burst.

These facts when coupled with ease of aiming and throwing, made this seem an effective weapon for limited use wherever an attack with fragmentation grenades could be improved by an interspersal of WP. The user had little to fear from the burst, because the fragmentation of the thin aluminum case produced only large fragments, which quickly lost their velocity. Only the filler bushing and the brass parts of the fuze could travel distances of as much as 60 yd.

The decision to accept WP splashes of ¼ to ½ in. or larger as casualty producing was based on many reports issued by both the British and American Armies. The amount of WP sought was, therefore, a minimum of about 150 mg,[14] a quantity which would burn through at least two layers of battle dress. Smaller particles would be considered chiefly harrassing, unless they happened to hit some unprotected part of the body. Naturally, several simultaneous hits would be more than correspondingly effective, thus giving point to the discussion of density of hits.[4]

Chapter 5

SPIGOT MORTAR

5.1 INTRODUCTION [1]

The weapon described in this chapter is, in the writer's opinion, quite novel, although the principle of the spigot has been applied before and weapons based on it are well known. The Spigot Mortar was originated by a group in Britain known as the Inter-Services Research Bureau, who had carried it into full production in Britain but on a scale too small to supply American, as well as British, requirements. At the request of OSS, and with the full support and cooperation of the British,[2] Division 19 assumed the task of supplying to interested Services sufficient American samples for an appraisal of the place of the Spigot Mortar in American operations. The groups thus acquainted with the device included the Army Ground Forces, the Army Ordnance, the Bureau of Ordnance, and the Marine Corps. Samples were eventually despatched to the Infantry Board at Fort Benning, Georgia,[3] and to the Aberdeen Proving Ground, Aberdeen, Maryland, but the reports of these groups were not available at the time of writing this chapter.

The Spigot Mortar was a weapon capable of throwing accurately a projectile, carrying 3.1 lb of high explosive and an impact fuze, over a distance of 200 yd or less without appreciable noise or flash. These last two features were the ones which made the device unique and recommended its consideration in a number of special operations, which might logically include attack on fixed installations, either by time delay or manual operation, or on moving targets by booby traps. Because of the noiseless and flashless features and the element of surprise, the danger of discovery could be considered negligible.

The total weight of the gun, sight, and one bomb did not exceed 12 lb, making it easy for an individual soldier to operate effectively against specially selected targets, and to carry, if desired, more than one round. In some ways, the Spigot Mortar can be considered a useful complement to the rocket launcher described in Section 1.3. It definitely should not be considered a competitor, because its range is much shorter and the rocket is extremely noisy.

As ordinarily used, the mortar required a tree or other support, such as a masonry wall or a pole, for attaching the gun and absorbing the not inconsiderable recoil. This limitation on its usefulness was not considered serious and was partially rectified by the development of a plate support allowing the firing of the gun at all locations on solid ground.

The Spigot Mortar was in production by OSS at the end of the war. So far as is known, it did not reach the field for combat use.

5.2 THE GUN [1,4]

The gun consisted essentially of a base and a 3/4 in. spigot and weighed in all 4 3/4 lb. The base was provided with a screw so that it might be screwed by hand into a support, which was generally a tree of over 6-in. diameter. As an aid in removing bark and obtaining a smooth bearing surface for the base, one of the two 4½-in. lever arms had a chisel ending. The other arm was provided with a hole through which a trip wire could be guided when booby trap firing was preferred.

The spigot was attached and mounted at the base by a ball and socket joint composed of the spherical head of the screw and a cover plate held to the base by three screws, two of which were simple cap screws ordinarily remaining fixed at a preselected adjustment. The third screw was provided with a movable T-handle which, when loose, allowed free movement of the spigot in the ball and socket joint, but, when tightened by a turn of the wrist, locked the spigot in the desired location.

The spigot was hollow and housed a spring-actuated striker which was cocked by a simple pull on a lanyard and held in cocked position by a trigger. The spigot tube was mounted firmly in the base and delivered to it the thrust produced by firing the round. This was accomplished by the release of the trigger, which allowed the compressed spring to propel the firing pin forward. The small pointed end of the firing pin projected through a small hole in the forward end of the spigot tube and struck the sensitive primer cap of the propellent cartridge in the bomb tail.

The maximum elevation allowed when using a vertical support for the gun was about 23 degrees, giving an effective range of slightly over 200 yd. An assembled gun and the various parts referred to above are shown in Figure 1.

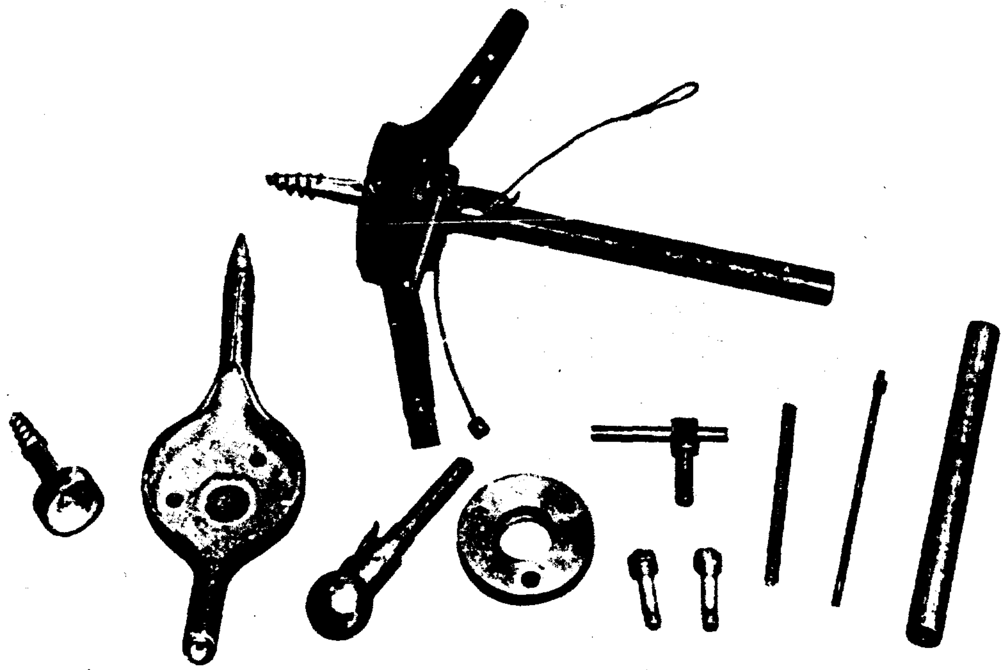

FIGURE 1. Spigot and component parts.

No new principles were involved in the construction of the sheet steel (No. 14 gauge) plate-mounting which allowed the use of the gun where no support other than firm ground was available. The gun was mounted in a plate by means of a trunnion and two bearings, allowing a greatly increased traverse for aiming in the vertical plane. The plate was so constructed that the two circular rings would cut into the earth when the plate was seated by rotation and oscillation. One trial shot was generally sufficient to embed the plate solidly in the ground, where it could then be more firmly held by driving in spikes. Removal required very little effort.

5.3 THE SIGHT [1,6]

The sight, as shown in Figure 4, slid over the spigot tube and was fixed in position during aiming by a locking screw. After the gun was positioned and secured, the sight was removed and replaced by the bomb. Figure 2 shows this sight, in two views mounted on a spigot tube as though in use, and in the third folded for carrying. Folded, it measured $1^{11}/_{16}$ in. thick, $3^{3}/_{8}$ in. wide, $5^{5}/_{8}$ in. long, and it weighed about 1.2 lb. This sight was entirely an American development and was a simplification of the British design.[6] The one shown was for the tree-mounted gun. A modification for high angle trajectory fire would be needed for the plate-mounted gun.

Ordinary use of the sight required its positioning as seen in the upper left view of Figure 2. The user standing back to the target and bent over saw an erect image while both his hands were free to adjust the gun. The sight was a one-power, right-angle telescope calibrated in 25-yd increments by the use of the peep-hole bored sight shown in the lower right corner of Figure 2. In those cases when the operator wished to sight from cover, such as tall grass, a trench, or foxhole, the eyepiece was turned downward, as shown in the lower left view. However, the body of the sight was always mounted vertically above the spigot tube. In all cases crosshairs marked the target.

5.4 THE LIVE BOMB

Figure 3 shows the assembled bomb and the various component parts, exclusive of the propellent

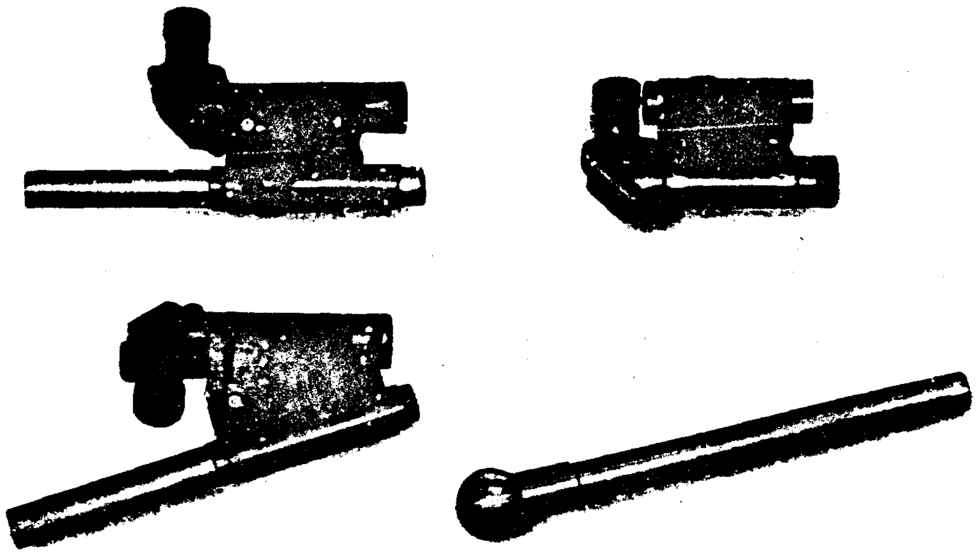

FIGURE 2. Sight.

cartridge. The bomb consisted of a tubular tail carrying a propellent cartridge, a silencing wad made of soft brass, a screw-cap end-piece and a dust plug, an impact fuze and its housing, and a soft steel head with cap opening for filling with high explosive. The head was attached to the tail by locking the hooks on the underside of the head into a plate located in the cone of the tail.

5.1.1 The Tail

The most difficult part of the whole weapon to provide was the tail tubing, for this had to withstand the tremendous pressures developed by gases from the burning propellent cartridge, and to seal them completely from the air. It was this which made the weapon flashless and noiseless, the unique features which gave it its chief value. The tube shown was found by actual tests to withstand pressures below 49,000 psi, a safety factor of 2.5, which allowed the possible increase of the propellent charge by perhaps 60 per cent, with probably attendant increase in range to 275 yd.[7] No development along these lines was completed because of time limitations, but future work of this kind would seem profitable, and it would doubtless entail a strengthening of the gun mount.

The tail tubing was built up of three seamless steel tubes of SAE 3140 specification sweated together and sealed with a thick steel plug silver-soldered in place.

5.1.2 The Cartridge

This was a specially constructed 12-gauge cartridge (FLI-S18), consisting of a cylindrical paper tube, a copper cap (outer base), and an aluminum and composition disk (inner base) bearing in its center a detonator. The filling was a special nitrocellulose mixture developed for the purpose by the Federal Laboratories of Pittsburgh, Pennsylvania, and its waterproofness was assured by a double coating of Sargent Paraffin Hard.[11]

The cartridge, assembled in the bomb tail and backed by a soft brass wad bearing a small hole to allow penetration of the firing pin contained in the spigot, was fired by the blow, with a resultant acceleration of between 1,800 and 2,200 g on the bomb, thus imparting an initial velocity of about 200 ft per sec. The pressure generated by the burning of the cartridge forced its copper base cap and the adjacent wad down the tail tube, where they came to rest against the screwed-in stop ring in the base of the tail. An essentially gas-tight seal resulted and the necessity for overlapping tail-tube construction is now explained.

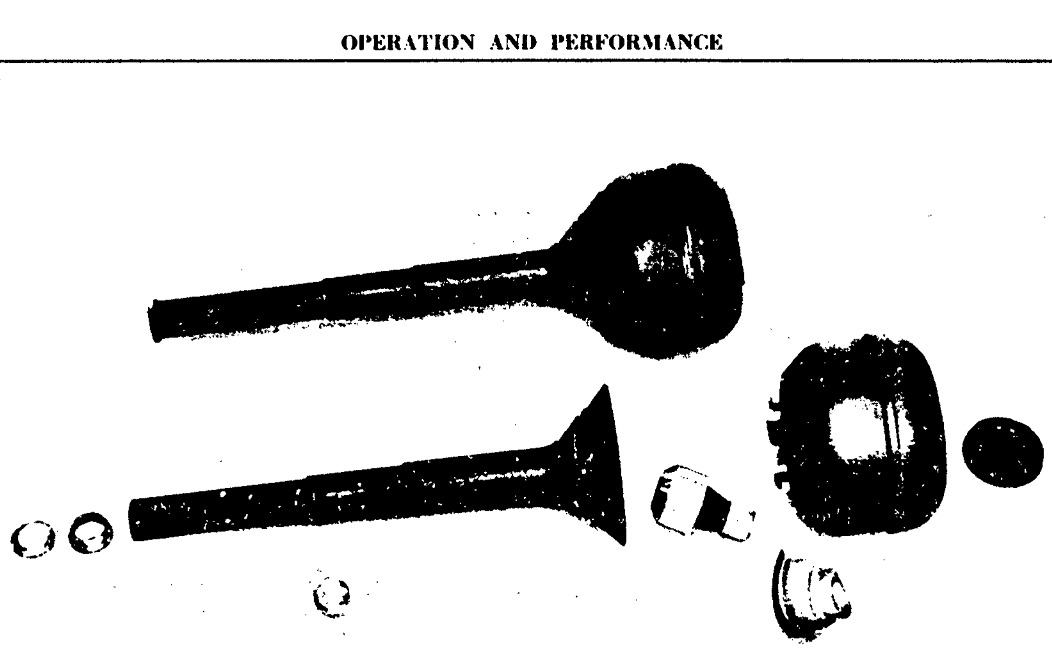

FIGURE 3. Bomb and component parts.

5.4.3 The Fuze

Delays in delivery and certain inconsistent performance by the British fuzes [3] prompted a study of this part and the development of an American fuze based on the T-5 (see Section 3.4). This American fuze was armed by the release of an inertia pin operating under application of about 122 g, a force well beyond anything likely to be encountered accidentally, and yet sufficiently below that given by the cartridge to assure certain functioning. To prevent firing from rearward movement (which might occur when the wad and cartridge base met the stop ring), the "all ways" features of the T-5 fuze were sacrificed, with the result that firing was not always obtained on glancing impacts of low angle.[8] Calculations indicated that the fuze became armed before the bomb had entirely left the gun, a feature which could perhaps be corrected by an alternate design which would provide arming after an elapsed time of 1 or 2 sec. Such a fuze did not exist in Ordnance procurement at the time of this development and would have great advantages in many munitions, if it could be developed. A very preliminary attempt was made to solve the problem.[12]

5.4.4 The Head

Two bomb heads were constructed, one to use with a poured charge and one to use with a molded charge, the latter type being preferred by the Americans while the former type was standard with the British. Both were made of light steel stampings and contained a soft brass insert to house the fuze. In practice, it was found that the light steel cover made very close contact with the target before the fuze had time to operate and thus insured optimum performance of the high explosive. A filler plug sealed the head after it was filled.

It was shown that filling of the heads could be done practically, either prior to delivery using cast pentolite [10] or in the field with plastic explosive (Composition C-2).[9]

5.5 OPERATION AND PERFORMANCE

The user, having screwed the gun into a suitable large tree, having aimed the spigot with the sight, and having replaced the sight with a loaded bomb, had the choice of three firing methods: the first was by manual operation of the trigger release cord; the second was by use of a time delay Pencil (see Chapter 9), from which the spring snout had been removed to allow free passage of the delay plunger against the trigger of the gun; the third was by the connection to the trigger release of a trip wire, as in standard booby-trap practice.

The muzzle velocity was determined by firing through Boulange screens 18 ft apart. Its mean value

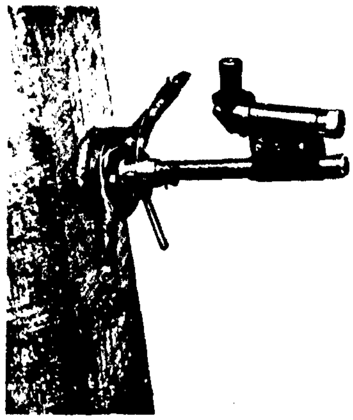

FIGURE 4. Spigot with sight.

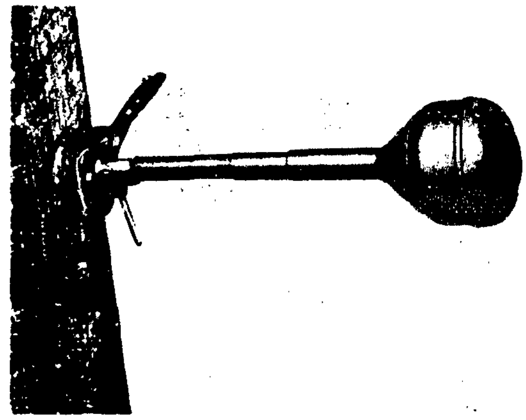

FIGURE 5. Spigot with bomb.

was 195.6 ft per sec with a mean deviation of 0.69 per cent, which corresponds to a deviation in range of 1.4 per cent. The mean deviations observed with inert filled bombs were 7.4 per cent at 50 yd, 1.5 per cent at 100 yd, and 1.3 per cent at 150 yd. This indicated that at these ranges the deviation was caused by varying muzzle velocity and was attributed to variation in the performance of the propellent cartridges. Wind direction had some effect, as could be predicted, for such a large and relatively slow projectile, but could be compensated for by an experienced operator. Disregarding this, a 100-yd range gave deviations in elevation and line of approximately ± 2 ft and ± 1 ft, and was regarded as the maximum effective range for targets as small as tanks or automobiles.[4]

Tests with trained personnel indicated that the Spigot Mortar could be removed from a carrying rucksack, mounted, aimed, and fired within 2 to 4 minutes.

The effectiveness of the charge against various targets can be judged from the following: (1) on 2- to 2½-in. armor plate, blisters with a 14 in. diameter were projected from the back of the plate and a hole 5 in. in diameter was made through the plate; (2) on reinforced concrete 9 in. thick, an opening of 18 to 24 in. resulted; (3) an automobile was completely demolished; and (4) a locomotive was so damaged that it required a month's repair.[5]

It is believed that a most effective and novel weapon was developed and that, in special operations, it could harass the enemy seriously.

Chapter 6

SLOW BURNING EXPLOSIVES (SBX)

6.1 INTRODUCTION

The work of Division 19 on SBX originated in a search for unconventional and yet readily available materials which would be capable of inflicting severe damage to enclosed structures, such as storage warehouses and ship's holds. The hazards common to industries handling finely divided carbonaceous materials immediately suggested that dust explosions, properly controlled and produced, might be a valuable military technique. This thought was not original with the division, since a large amount of work had already been done in England, chiefly on coal dust,[20] with, from the theoretical point of view, slightly disappointing results.

In this country, a study of many years duration had been underway at the Bureau of Mines and this also centered primarily on coal dust, although many other materials, including fine organic and metallic dusts, had been investigated to a more limited extent.[2] It was thus well known [1] that practically all finely divided combustible materials, if properly dispersed and mixed with air in correct proportions, would burn, when ignited, with a violence and speed of possibly explosive proportions.

The difference between inflammability and explosibility, being one of degree rather than kind, the following experimental quantities were indices of the course to be followed: (1) relative inflammability should be high for a military explosive, (2) limit of explosibility should be low, (3) the pressure developed would depend on both the heat of combustion and the ventage of the chamber where the explosion would take place, and (4) the rate of pressure increase would be a measure of the speed of combustion. The last point indicates the chief difference between high explosives and SBX, SBX being of military value only in those cases where the maximum pressure effect over a relatively long time is important, or where ventage is small and confinement good. In so far as heat of combustion is concerned, high explosives are in no way comparable to combustible dusts, as indicated in kg-cal per g for the following materials: black powder, 0.7; dynamite (75 per cent), 1.3; TNT, 3.6; coal, 7.6; pitch, 8.4; aluminum, 14.1; magnesium, 6.0; and sulfur, 2.2.

With this background of work in mind, the central laboratory of the division conducted experiments on the development of a dust disperser and igniter, and studied a number of materials which in dispersed form might give suitable performance in confined space. The work was done with no thought of more orthodox military applications and it does not appear that SBX can seriously compete with high explosives for use in bombs or shells. The effectiveness of SBX is limited to confined structures where the ventage is small, and by hazards in its loading, and the number of likely targets. However, where a special target has been selected for attack or demolition by a small group of specialists, SBX would appear superior to high explosives, both because of its availability in the field and because its slow pressure increase in a confined space might eventually cause greater damage through structural failure than would a comparable amount of fast acting high explosive whose effect would be to punch or cut rather than demolish.[7]

This new work of Division 19 with the cooperation of Division 2 and Division 11 personnel resulted in two major developments: the new SBX material called Salex [10, 11, 12] (a compressed mixture of sulfur and aluminum), and Lulu,[1, 5] a disperser-igniter for use with all SBX materials. In the course of the work, many different substances were tested using a number of measuring gauges, two special explosion-proof rooms, wooden buildings, and a ship. From this work it was concluded that Salex was not as effective, on either a weight or volume basis, as a number of other SBX substances, chief of which were aluminum and gasoline when dispersed and ignited by Lulu. This igniter, being small and simple to construct, was believed valuable for certain uses of a clandestine nature. If necessary, it could even be dispensed with by the use in the field of suitably cased Torpex or TNT blocks. In brief, a method for attack on closed structures was discovered and the tools best suited for the purpose were made available.

6.2 SBX MATERIALS [4,14]

There is no scarcity of common materials which can be used for this purpose. An early British memorandum lists, for example, 35 different substances likely to occur in manufacturing plants, to disperse easily, and then to ignite explosively with a small heat source such as a lighted match. In addition, it

lists 19 more, which will behave similarly when exposed to higher heat.[4] Almost all of these SBX materials were organic and carbonaceous, and, of them all, flour seemed most available and worth trial. Early trials with 5-lb sacks indicated that dispersal was best obtained using 75 or 100-g charges of TNT, and that black powder and blasting powder were not uniform or complete in action. As was to be expected from the Bureau of Mines work,[2] no ignition of dispersed flour dust was obtained by using TNT alone. It was obtained, however, when the high explosive was surrounded by coarse magnesium flakes,[3] and this was the origin of Lulu (Section 6.3).

Other carbohydrate dusts, including graham flour, starch, and sugar, gave results comparable with those of white flour. In general their efficiency was low (about 20 per cent), when compared, by assuming values of peak pressure, or impulse, and time of burning, with calculations made from a simplified theory of SBX.[15] By assuming that SBX pressure arises solely from temperature increase, that all the heat of combustion is used in this way, that burning is at a uniform rate, and that the ratio of maximum SBX pressure to atmospheric pressure is small, expressions dependent on the volume of confined space, the ventage, the chemical nature of the SBX material, the heat of combustion, and the charge size were derived. Efficiency is the value thus calculated, compared to that actually obtained from measurements of the total impulse and pressure-time curves.

Low efficiency may be accounted for by energy losses: first, because part of the charge may have escaped complete combustion through loss in ventage or unfavorable combustion conditions, secondly, because of variation in the ease with which a given SBX material can be completely burned, and thirdly, because of the large loss of radiant heat to the cold walls of the test structure. In all SBX materials, these three important points are difficult to evaluate, the second one only being a function of the chemical nature of the combustible substance. In the case of carbohydrates, such as flour, the second factor is apparently very large. At any rate these materials are poor for SBX purposes.

The efficiency of both coal and hydrocarbon dusts was nearly 20 per cent, while that of metal dusts (aluminum and magnesium) was about 35 per cent, flaked aluminum being superior on a weight basis and atomized aluminum being preferable on a volume basis. These were definitely inferior to liquid SBX materials, such as benzene and gasoline, the efficiency of which was 35 to 40 per cent, and carbon disulfide, the efficiency of which reached 70 per cent. However, in the case of these liquids, there was a long induction period (at least when Lulu was the disperser-igniter) which, with moderate ventage, resulted in loss of pressure.

A combination of aluminum dust and liquid SBX materials was shown to eliminate this trouble entirely and, at the same time, to increase the apparent density. For example, 10 lb of aluminum and gasoline mixture (d 1.25) per 8,000 cu ft volume gives an SBX pressure of 15 to 20 psi (1–3 lb was considered sufficient to demolish an ordinary masonry or wooden structure).

An attempt to produce a mixture of sulfur and aluminum which would supposedly show the theoretical maximum effect was not entirely successful. The optimum combination of Salex, in either a cased or uncased unit, contained 75 to 85 per cent aluminum compressed with sulfur to 3,000 psi and a disperser-igniter of tetryl representing 10 to 25 per cent of the total unit by weight. For such a munition, the calculated total heat of combustion was two-thirds more than that for a similar weight of TNT, but this energy could not be freed completely.[17] Many variations in the relative proportions of the two ingredients, in the burster charge, in the type of case, and in the addition of carbon disulfide, failed to improve efficiency, which was always below TNT when used without additional SBX material, and always below Lulu when used with SBX material. Only tactically, in that it formed a non-persistent poison gas, did Salex have any attraction over other SBX materials.[10]

Typical time-pressure curves for the various SBX substances tested, and, in some instances, the calculated performance curves are given in Figure 1. The value for Salex would be between the values for tetryl and flaked aluminum.

6.3 DISPERSER-IGNITER (LULU)[6,9]

Having discovered that high explosive was, by a large factor, superior as a disperser to black powder or blasting caps, and having ascertained that a surround of magnesium chips was needed to insure ignition of the dispersed dust-air mixture, a more exact definition of the high explosive, the amount and specification of the surround, the type of casing for the complete unit, and the size of the Lulu best suited for convenient amounts of SBX material, was needed. It

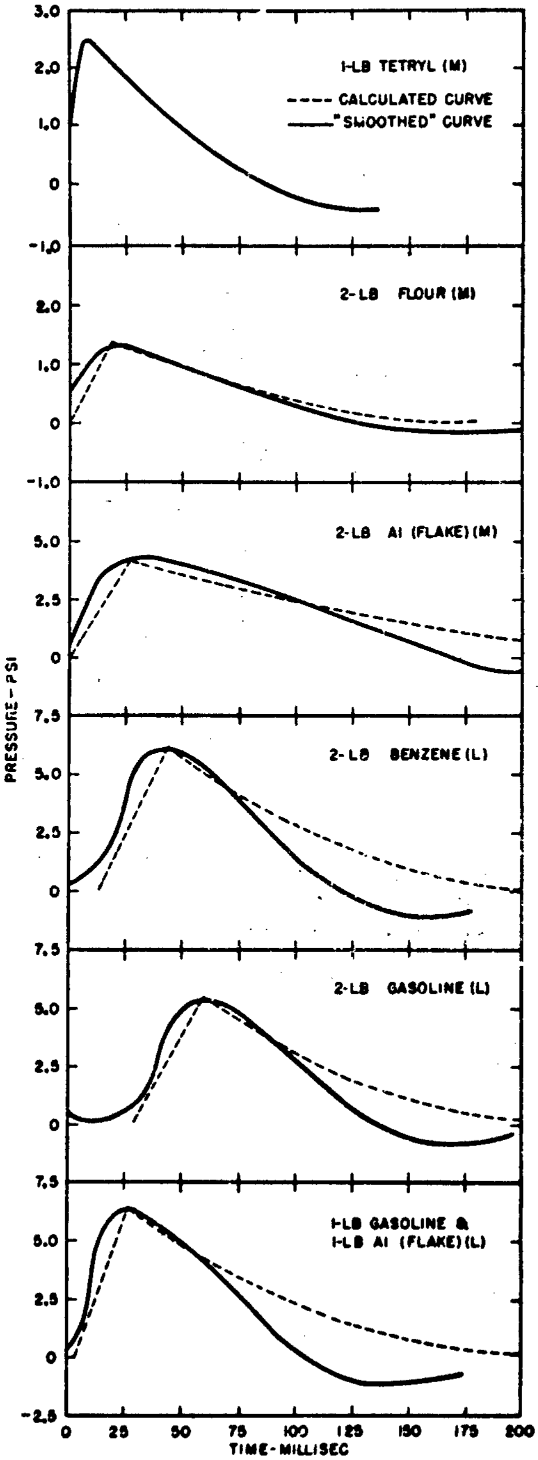

FIGURE 1. Comparison of results of theoretical calculations of SBX pressure-time characteristics with actual studies.

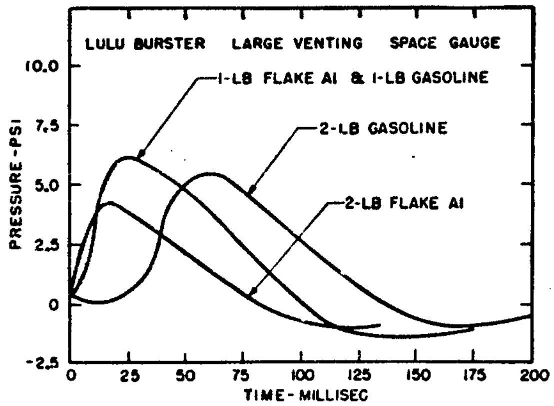

FIGURE 2. Effect of mixing aluminum with gasoline using Lulu burster, large venting and space gauge.

was soon apparent that magnesium flakes, while desirable and in no case harmful, were unnecessary in the better SBX substances, such as gasoline, but were essential for the poorer ones, such as flour. In the final model, therefore, magnesium in sufficient amount to insure good performance with flour was specified.

It was found also that the case could be, equally well, cardboard, steel, or aluminum, so far as dispersing and igniting were concerned. In the final model, aluminum was chosen for its lightness and availability and its tightness against the liquids, preferred as SBX charges. (It will be remembered that some high explosives are soluble in gasoline or benzene.) Without loss of performance, the choice of high explosive might well have been TNT, tetryl, or Torpex, for all three produced identical results, but, because of cheapness and availability, TNT was specified.

The final Lulu disperser-igniter consisted of 360 ± 5 g of a 60-30-10 mixture of granular TNT, magnesium Grade C, and magnesium Grade B loosely packed into an aluminum casing (Alcoa 24 ST 16 gauge, round tubing 2 in. OD and 12 in. long) carrying screw caps (24 threads per in.) at both ends. Holes were there provided for shipping plugs which could be removed and replaced by the initiating system consisting of a booster assembly (TIE2 or British Type 6) and a delay mechanism such as a clockwork or a-c delay (see Chapters 12 and 13) or a standard engineer pull switch for lanyard operation or booby trapping.

This standard Lulu was too large for convenient testing and most of the results recorded here were obtained with scaled down charges and the so-called

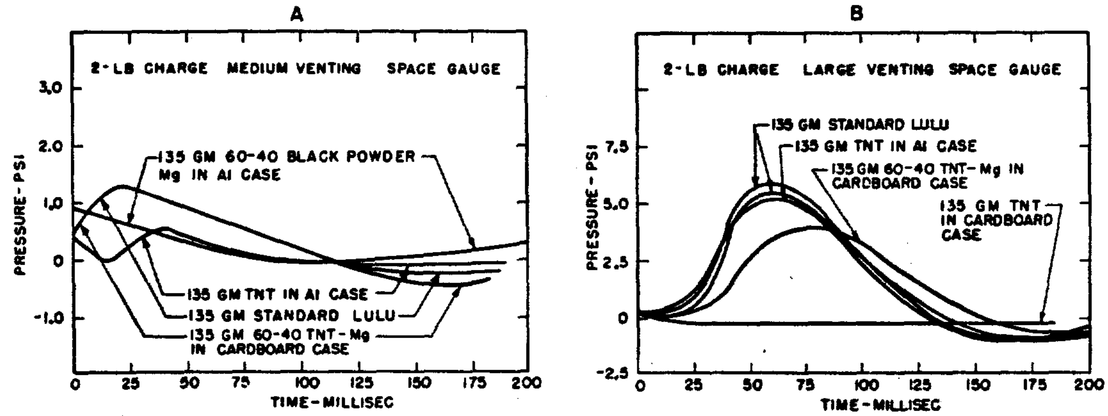

FIGURE 3. Comparison of disperser-igniters. A. Effect of nature of burster with flour. B. Effect of nature of burster with gasoline.

Baby Lulu, a similar unit containing only 135 g of the TNT mixture. The standard unit was adequate for dispersing and detonating about 100 lb of flour and similar dusts, or several gallons of liquid. Since these materials were readily obtainable in military dumps, the Lulu weighing only 2 lb could be recommended for field use by an individual soldier. Without burdening, it gave him a powerful weapon for special use.

This, of course, could not apply to Salex, which was in the nature of an SBX material itself and was very inefficient for dispersal and ignition of other materials.

6.1 VENTING

Of paramount interest in SBX discussion, is the amount of venting or the ratio of vent area to enclosed volume. The general effects for extreme cases are easily foreseen. In the open, an SBX bomb would spend itself harmlessly and, because of its low speed of detonation, could not be counted on to throw fragments of casing or shrapnel forcefully over a distance comparable with that for high explosives. In the other extreme case, where no venting is available, the pressure on the walls of the confining structure would become enormous and, when the limit of their elasticity had been passed, would collapse with complete demolition of the structure. This would be a most favorable case for SBX, and one in which high explosives would not perform so well, because of their low heats of combustion and the shattering speed with which they detonate.

A choice of the correct amount of SBX material for a given volume depended, therefore, on the ventage for that volume and the other factors inherent in SBX which have been mentioned in Section 6.2. Figure 4 shows the effects of varied charge sizes for constant venting, while Figure 5 shows the effect of changed venting for constant charge.

The curves are based on data obtained from the use of a specially constructed underground testhouse, a concrete structure measuring 30 ft in length, and having a total capacity of approximately 4,320 cu ft. The open end and a part of the adjacent roof were provided with movable shutters and planking so that the opening could be controlled at will. The three openings most commonly used were 10, 20, and 40 sq ft, and designated small (S), medium (M), and large (L), respectively. For the more inefficient SBX materials, the M opening was used; for gasoline and aluminum and mixtures of them, the L opening was necessary to protect the structure from damage.[16] The position of the charge within the structure was irrelevant, because the pressure obeyed hydrostatic laws.

A quantitative recommendation to the field was difficult but was about 0.05 oz per cu ft.[5] In a structure or space with approximately M ventage, the action of a 100-lb bag of flour on a volume of about 10,000 cu ft insures demolition. The same result would also be obtained with a gallon (about 30 lb) of gasoline or a sludge of aluminum powder and gasoline, and such materials would be expected to build up slowly (in 10 to 15 milliseconds) to a maximum pressure of several pounds per square inch and to maintain that pressure for a period of perhaps 50 milliseconds, a time which would certainly be sufficient to demolish all but the strongest construction. Even a

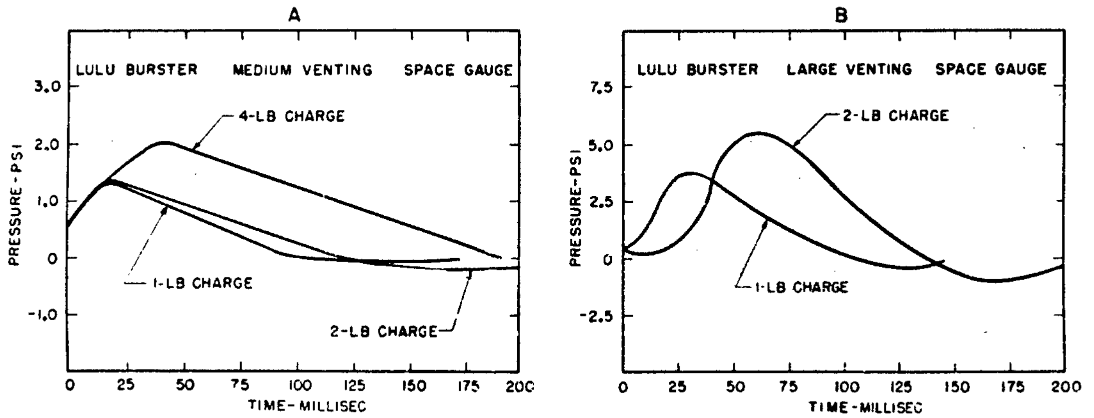

FIGURE 4. Comparison of charge size and venting. A. Effect of charge size with flour. B. Effect of charge size with gasoline.

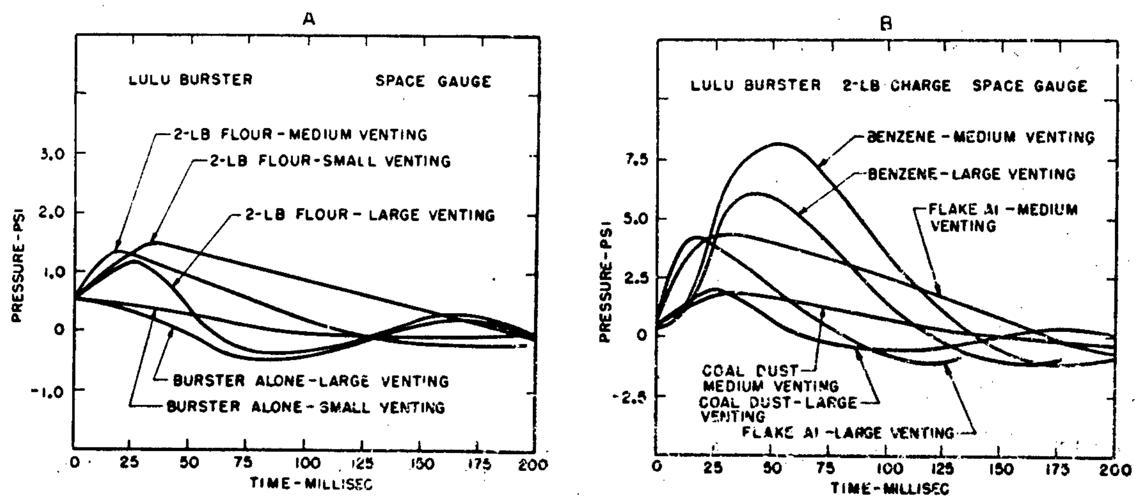

FIGURE 5. Comparison of charge size and venting. A. Effect of venting with flour. B. Effect of venting with various materials.

structure with a number of glass windows could be considered closed, for while the glass would break easily under a sudden blow (such as from a high explosive) it would withstand for a considerable time the slow increase in pressure provided by SBX, and, in the end, the masonry could be expected to yield first.[12]

6.5 INSTRUMENTS FOR EVALUATION OF SBX [8,13,16]

An accurate measurement of the peak pressures, as well as the intermediate pressures, at various times was essential for an appraisal of SBX substances. This was accomplished by using a number of different gauges which gave fairly consistent results, so that there was reason to believe that the quantitative comparisons inferred had a firm basis in fact.[15]

For the study of the characteristics of underwater explosive waves, Division 2 had developed tourmaline piezoelectric gauges which, through the cooperation of this division, were found satisfactory for SBX study and superior to similar Rochelle salt gauges, commercially available. After thermal insulation to prevent spurious pyroelectric signals, these gauges gave most satisfactory performance.

A second type gauge, based on a condenser of General Motors design [21] gave continuous time pressure curves comparable to the tourmaline gauges.

A third type developed by the Factory Mutual Research Corporation [13] was based on a mechanical principle and consisted essentially of a piston, the

mass of which per unit area was equal to that of the structure under investigation, and a spring, which with the piston executed vibrations at a natural frequency typical of that structure.

A fourth gauge used with success was based on the simple mechanics of the expelling of a projectile of known mass from a tube inserted in the side of the test structure. The distance over which the projectile was thrown was a measure of the pressure per unit area imposed on the interior walls by SBX.

A modification of this fourth type was devised, but not extensively used. Essentially, it consisted of a car of known mass which moved with minimum friction in a brass tube. Its velocity was determined by timing its transit through two electric contacts separated by a fixed distance and with a thyratron circuit supplied to start and stop an electric impulse-counter. This gauge was readily adapted to explosions of varying degrees.[16]

All the gauges gave trouble and were not always in agreement. It is believed that no new fundamental design was involved in any of them.

6.6 FIELD PERFORMANCE

Two large-scale demonstrations of the effectiveness of SBX were conducted: one against several wooden houses of varied ventage, and the other against a wooden vessel having two holds of about 2,000 and 10,000 cu ft capacities. The more spectacular results were obtained using flour and the Lulu disperser-igniter on houses made available by operations of the Tennessee Valley Authority.[7]

For example, when a two-story building, in fair condition, measuring approximately 30,000 cu ft, and with windows boarded up to secure minimum ventage, was attacked with a 95-lb bag of flour, and the standard Lulu detonated electrically, complete demolition resulted. Although a huge ball of flame enveloped the collapsing building, no fire resulted. The view in Figure 6 was caught by the camera at the moment when the SBX had lifted the roof and was pushing out the walls. Figure 7 shows the interior of the building at the moment when the SBX is near its maximum effectiveness. The accompanying flames can be clearly seen.

A similar trial on a solid wooden house, with a number of interior partitions and much ventage, resulted in a dangerous condition, but not demolition. Small Salex charges, located similarly in old dwellings, did less damage but provided sufficient sulfur dioxide fumes to render occupancy impossible, in spite of free ventilation, for some time after the explosion. In a bunker or enclosed trench, the effectiveness of Salex is unquestioned. Whether such use would constitute chemical warfare is a matter for Service definition.[10]

As might have been expected, the results obtained in the well-enclosed hold of a derelict, but sound, wooden lugger were quite gratifying. A standard Lulu, detonated electrically, dispersed and ignited 90 lb of flour with a resultant lifting of the deck throughout its whole length, splitting of the planks adjacent to the hull, and blowing away of the caulking. The badly sprung and leaking hulk caught fire from the accompanying ball of flame and burned to the water line as it sank. Had the vessel been at sea it is believed that nothing could have saved it. The heaving deck and the escaping flames are shown in Figure 8.[8]

FIGURE 6. Lulu — explosion in wooden house.

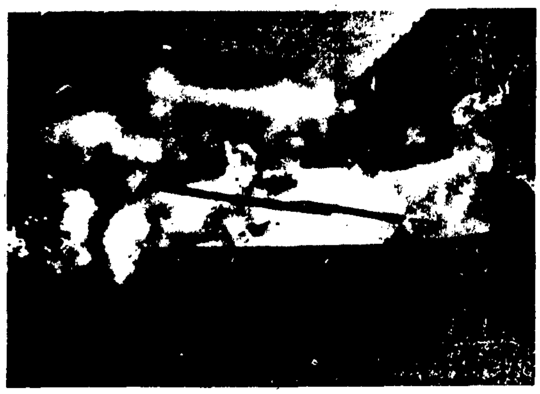

FIGURE 7. Lulu — explosion in wooden house showing flame.

FIGURE 8. Lulu — explosion in wooden ship.

6.7 FAST BURNING INCENDIARY (FBI)

The difference between a Slow Burning Explosive (SBX) and a Fast Burning Incendiary (FBI) is one of degree. In the former the presence of a ball of flame is unavoidable and of secondary importance, while in the latter it becomes the chief feature and the blast effect is repressed. That this could be easily accomplished by a suitable choice of conditions was demonstrated in England [18] and repeated in this country without difficulty [19] on small wooden structures. The tactical limitations of FBI are similar to those already explored in Section 6.1, and it is not clear that FBI would be useful on any large scale as a filling for conventional bombs. However, as a special tool for attack by commando troops on particular combustible targets, it has much to recommend it, for the fire produced is so nearly instantaneous and the area set afire at one time so large that a successful defense is hard to imagine.

The charge usually employed weighed about 20 lb for a wooden hut measuring 13 × 9 × 8 ft and consisted entirely of grade 0 magnesium and a small amount of magnesium turnings. Two pounds of gun powder were ignited by Bickford fuze. An almost silent flash resulted and a minor explosion, caused by the SBX effect, provided small openings which increased the draft. Five seconds after the burst, the entire structure was enveloped in flames and all the interior walls were afire. Four minutes later, the structure collapsed and in seven minutes was nearly entirely consumed.[18] Figure 9 shows the course of this experiment.

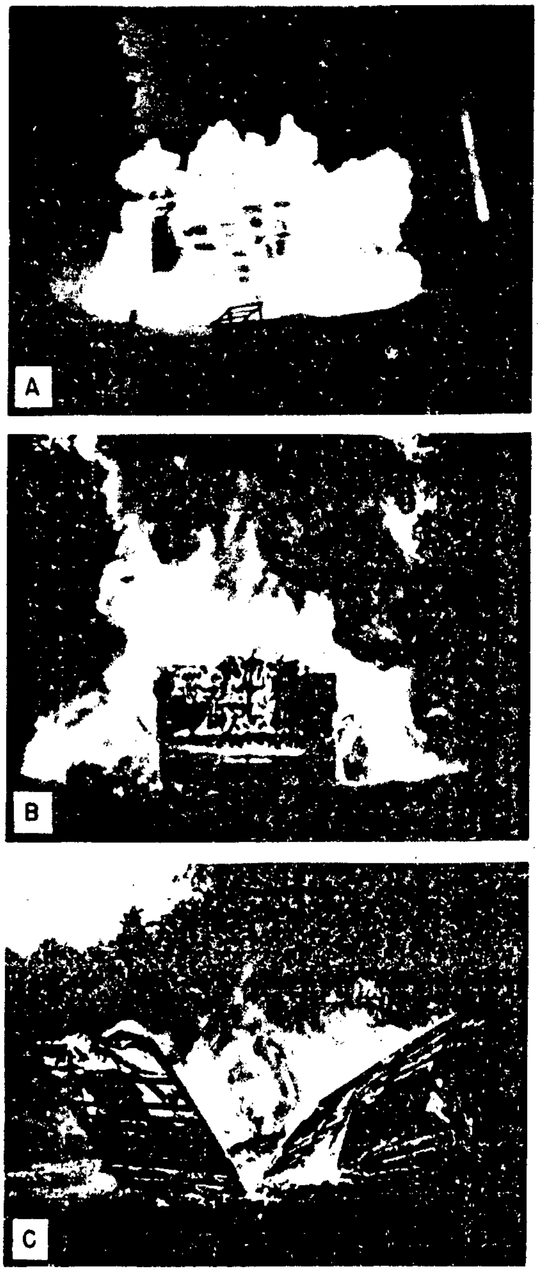

FIGURE 9. Ignition of a wooden hut by fast burning incendiary.

It is apparent that the ratio of effective charge to volume of structure is much higher for FBI than for SBX, thus limiting the size of buildings which could be attacked in this way.

Chapter 7

SPECIAL REMOTE-FIRING DEVICES (NR–109)

The simple devices described in this chapter were intended for deceptive use by guerilla groups, patrols, and small maneuvering forces, such as those employed by the Marines and OSS. They were intended to deceive the enemy as to the correct location of the group, and to trap him into revealing his own well concealed position. It was proposed that a number of these devices (Bushmaster) be planted surreptitiously on one flank, and upon their actuation and the enemy's presumed reaction, that an attack be made from the other flank. By the use of trip wires and conventional booby-trapping techniques the devices could also be set to cover the approaches to a defensive area. The usual usage visualized, however, was with time delay actuation by means of the standard time Pencil (see Chapter 9).[4]

Originally, the requirement for Bushmaster was that: "It shall be small, portable, and self-actuating. It shall be capable of being installed by a single operator in a bushy terrain and shall functionally, after a predetermined time delay, vibrate or move the bushes and intermittently fire live bullets in a predetermined direction."

After early experiments with crude and heavy models,[1] a simple one-shot expendable unit was developed which met these specifications and was put into limited procurement by OSS. Its extreme simplicity is shown by Figure 1.[2] It consisted of a short length of gas pipe (7 to 8 in.) reamed at one end so as to chamber a cartridge (.45 caliber, although others, such as .22 or .30, would be equally feasible with the appropriate sized pipe). This served as the gun barrel of the device. The breech was provided by a pipe cap drilled so as to hold a time Pencil (Chapter 9) without its spring snout and primer. The barrel was provided with a spring clip for attaching the device to small branches. When the time Pencil operated, its firing pin struck the primer in the base of the cartridge, as would the trigger of a gun, with sufficient force for reliable firing. The inevitable recoil which shook the supporting branch and the sound of the live bullet were thought likely to mislead the concealed enemy and to draw his fire, thus revealing his own position to the users of Bushmasters in hiding on the flank. For intermittent fire, several Bushmasters with different colored time Pencils could be planted simultaneously.

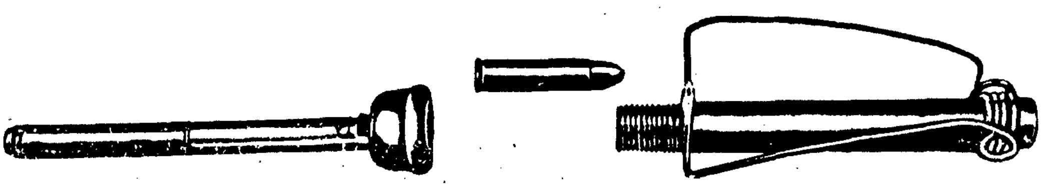

FIGURE 1. Single shot Bushmaster with wire clamp.

An attempt to produce a multiple-shot Bushmaster based on this design failed, because all the time Pencils were the same color and in such weakened condition that the firing of the first delay discharged the others as well. It was necessary to develop an entirely original device and this took the form of the simple clamp shown in Figure 2.

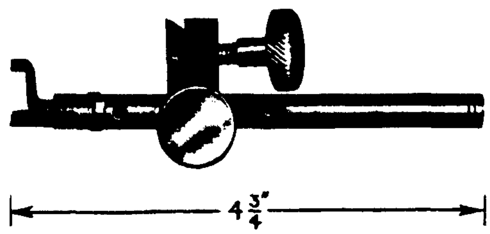

FIGURE 2. Pencil clamp for M-3 submachine gun.

A time Pencil, again minus its spring snout and primer, was attached by means of a simple screw-mount to the trigger guard of a standard M-3 submachine gun, so that the Pencil rested firmly against the trigger through a forked adapter. The gun was then mounted on a small tree. The firing pin of the time Pencil, upon striking the trigger, discharged the entire clip because of the constant and sufficient pressure exerted.

For booby-trap use, the multiple-shot Bushmaster was modified by the substitution of a standard pull switch for the time delay. Production of all three types was successful.[3]

PART II

SPECIAL FUZES

In Part II of the Summary Technical Report of Division 19, a few devices and several unsuccessful attempts to meet, by simple means, various field requirements, for initiating explosive and incendiary charges are discussed. The bulk of this work was concerned with time delay mechanisms, which probably will be of greatest value, for, as far as the writer is aware, research done in World War II on these small, simple, and very useful fuzes has not previously been gathered together.

In Chapter 9, the work done with the existing time Pencil is described in detail. In Chapter 10, the successful development of a substitute for this delay, having improved qualities of temperature independence and reproducibility, is discussed. Chapter 11 describes the simple conversion of either of the above time Pencils to incendiary fuzes with silent operation. Chapter 12 gives the details of several clockwork delay mechanisms covering a range of timings between 1 minute and 6 days, and, it is believed, that a previously existing gap in American munitions was thereby filled. Chapter 13 describes the unsuccessful attempts to develop time delays based on a variety of physical and chemical phenomena, and one delay, the so-called AC Delay (Acetone-Celluloid), which was produced and used in small numbers.

Chapters 8 and 14 give the results of work with two fuzes which were to be triggered by external forces at a preselected moment and which were not time delay devices. The first of these was a marine type known as the Concussion Detonator, which operated most successfully under water upon receipt of the explosive wave from an underwater explosion in the vicinity, thus allowing the simultaneous firing of many underwater charges. The other device, described in Chapter 14, was a radio-controlled switch intended to be operated by the receipt of a long signal with preselected characteristics. It was rendered safe against accidental triggering and provided with self-destructive and booby trapping features.

Some of the observations made in Chapter 1 apply to the devices described in this part of the STR. They were on the whole very small, simple in operation and construction, reliable, and best suited for use by individuals in special operations. These were naturally concerned mostly with demolition. The Service groups who expressed interest and followed this work of Division 19 were the Corps of Engineers, the Signal Corps, the Bureau of Ordnance, the Chemical Warfare Service, and OSS.

Chapter 8

SYMPATHETIC FUZE OR CONCUSSION DETONATOR

8.1 INTRODUCTION [1, 18, 24]

In both ground and underwater demolition work, it was frequently desirable that several charges of high explosive be detonated simultaneously. This could be accomplished by linking charges with Primacord, an operation which was not recommended, because of the time involved, the requirement of skilled personnel, and the clumsiness of the procedure. At the request of OSS, Division 19 personnel undertook the solution of this problem, basing their work on the development of a Sympathetic Fuze, which, on receiving the shock wave set up by the explosion of one charge, would initiate another charge. Such a fuze was successfully developed. In its underwater application, it was of interest and value to the Corps of Engineers working at the Engineer Board at Fort Belvoir, Virginia, and at Fort Pierce, Florida, as well as to the Navy's Underwater Demolition group. The problem of developing a Sympathetic Fuze for use in air was more difficult and the solution less satisfactory. Both types are described in this chapter.

The former was entirely mechanical in operation, while the latter, in its most sensitive form, employed batteries for initiating the charge electrically. The marine type was ultimately produced in quantity by the Engineer Board and was known to NDRC as the No. 66 Concussion Detonator. A very similar model, differing only in minor points, was produced by OSS and known as the No. 67 Concussion Detonator. The operation of both fuzes depended on the blow given a firing pin by a bimetallic click diaphragm, when it was struck by the concussion wave sent through water from an exploding charge.

Before these final models were perfected, preliminary fuze designs were made with frangible glass diaphragms. Section 8.2 describes this work in more detail.

The division was also concerned with the arming mechanism for both marine and air fuzes. For the former, the conventional salt block was improved upon by the development of the so-called Electrolytic Arming Disk (Section 8.4.2). For the latter, a somewhat similar arming was accomplished by forcing a constant viscosity liquid through a controlled orifice (see Section 8.4.3).

The material presented in this chapter describes a new type of fuze, valuable for many underwater uses and of interest, also, for demolition above water. The production of both the No. 66 and No. 67 fuzes was sufficient to demonstrate unequivocally that the Concussion Detonator was a safe and producible item.

8.2 PRELIMINARY DESIGN [18, 24] GLASS DIAPHRAGMS

Through the courtesy of British liaison officers, the division contractor was provided with a Sympathetic Detonator constructed on an inertia principle and having a maximum range of about 70 ft. This device consisted of several brass tubes containing as the sensitive member, a heavy weight, balanced on a cone pin and susceptible to the slightest jar. The device approached an antidisturbance fuze in nature. It was considered not altogether sound. American attempts to alter this design, by the incorporation of a glass diaphragm into the firing mechanism, indicated at once that too great a strain would be placed on the glass member and that the fuze would have a shock sensitivity so great as to be unsafe to handle. The British fuze was already open to this criticism and was, moreover, most variable in its performance. This fuze is illustrated in cross section in Figure 1,[18] and it can be seen that its functioning depends upon carefully releasing support from a weighted pin, the point of which rests on the point of the trigger for releasing the firing pin.

The principle of a frangible glass diaphragm, however, became the basis of several designs, of which the three most important are described in Sections 8.2.1, 8.2.2, and 8.2.3.

8.2.1 Direct Release [11, 18]

It was found possible to alter the standard release switch used by the Cor of Engineers so that its operation was restrained only by a piece of 0.006-in. glass of ⅞ sq in., supported only on its rim. Against this glass window, rested the standard split-sleeve pull-pin release mechanism contained in its watertight case. When submerged, this fuze failed to fire, only because of the very delicate support given the release mechanism by the thin glass window. The detonation of a high explosive charge within a radius of 50 ft at a depth of 5 ft or more was found to produce a sufficient shock wave in the medium to break

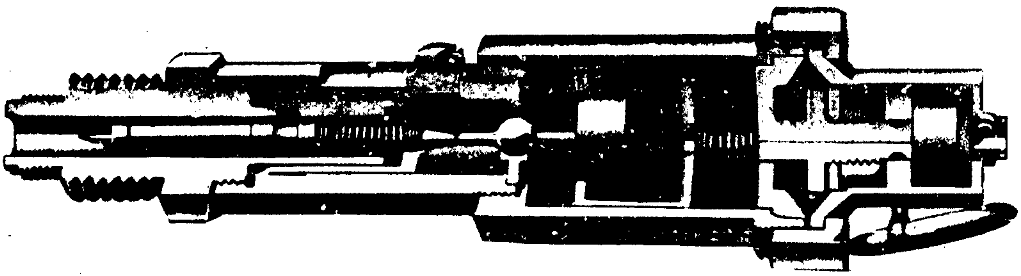

FIGURE 1. Inertia type Sympathetic Fuze.

this thin glass window and to release the firing pin. The design, however, was faulty. Entry of water into the actual firing mechanism frequently prevented normal functioning, and the glass windows were very sensitive to accidental dropping. Although the fuze had an arming system which prevented its firing under such conditions, it was not a practical design.

This prompted the development of further designs in which the firing mechanism did not rest directly upon the glass window and hence the glass was under no strain.

8.2.2 Indirect Release [17]

By retaining the Army's M1 pull type firing device as the mechanical basis and the glass window as the shock sensitive basis, a fuze was designed which rectified these two objections. All moving parts were completely enclosed within a waterproof casing, and the release mechanism was restrained by a secondary device, rather than by the glass diaphragm. This secondary device consisted of a pellet of compressed salts which was held in a small wire basket located in a chamber directly beneath the frangible glass diaphragm. So long as this salt pellet retained its strength, the release mechanism was unable to fire, but breakage of the glass window under water and entry of the water, resulted in almost instantaneous dissolution of the pellet and release of the firing mechanism. A suitable pellet made from Bromo-Seltzer had a weight of 40 mg, a diameter of 0.160 in., and a height of 0.156 in. Essentially instantaneous (that is, less than 0.5 sec) operation was obtained. In Figure 2,[17] illustrating this early model, the glass diaphragm is apparent and the small underlying wire container for the salt pellet appears. A standard salt block and pull ring provide safety.

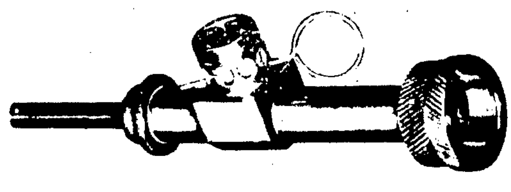

FIGURE 2. Indirect release, glass diaphragm type Sympathetic Fuze.

8.2.3 Electrical Firing [14,24]

Because of the necessity for a watertight inner compartment for the moving parts, which in manufacture might prove difficult, an electric model utilizing a simple sea cell was proposed. This consisted of a battery, lacking only the electrolyte for its operation and providing 1½ amp at 6 v upon the addition of a suitable electrolyte such as sea water. It was

proposed that in this design, upon the breaking of the glass window, sea water would be admitted to the sea switch, which, within a fraction of a second would deliver the electric current necessary to fire a standard electric blasting cap. The practicability of this approach was demonstrated, but the design was not perfected because the Armed Forces believed that dependence upon water of definite salinity would limit the usefulness of this design. Also, a requirement of 24-hour submersion in 20 ft of water was a definite handicap for any device of the glass window type, since it was found that glass, when under such continuous stress, would break after a given period, and that the glass of 0.006-in. thickness used in these three models would not withstand 15-ft pressure for that length of time.

8.3 METAL DIAPHRAGMS

8.3.1 Preliminary Designs [12,15,16]

It was suggested that the use of unequally stressed bimetallic diaphragms would have many advantages over glass ones, in that they would not be susceptible to the breakage or strain imposed by long submersion, and in operation would not allow the entry of sea water, thus making the design of a watertight fuze a simpler task.

A number of such models based on the M1 release type mechanism were constructed. The retention of the M1 device as the basis for design resulted in loss of simplicity, for it was found necessary to mount the metal diaphragm longitudinally to the firing pin and to transmit its energy through a trigger system. Apparently, this would be a complicated production matter. Largely because of this, the M1 release mechanism was abandoned as the basis for firing, but not before a number of experimental models had shown the soundness of the metallic diaphragm approach. Using 2¼-in. Phosphor bronze disks in water having a depth of 20 ft, operational ranges approximating 80 ft were obtained, when 2-lb charges were fired 3 ft below the surface. In many instances with fuzes similarly placed, operation at a distance of 500 ft was obtained. The range depended upon the diaphragm stiffness, and Table 1[15] illustrates this relationship, as determined in small-scale experimentation in air. In either air or water, orientation of the units with respect to the location of the charge appeared to be of minor importance.

TABLE 1. Relationship between range and diaphragm stiffness.

Diaphragm stiffness in pounds per square inch	Response range in feet from ½ pound TNT
9	7
4.5	10
0.75	18

A similar relationship between range and diaphragm stiffness was found to exist when the fuzes were operated in water, although a 9-lb diaphragm was considered the minimum for safety in water because of the requirement that the fuze not fire spontaneously at depths of less than 20 ft.

Several important basic designs resulted from experience with this early fuze. It was learned that the metal diaphragm should not be tightly clamped at the edges, but should be seated on a rubber washer which would serve to exclude water from the interior of the fuze. Also, for protection, the diaphragm should be covered with a thin rubber membrane with a negligible spring or snap action. It appeared too that the total internal air volume in the fuze should be several times the volume change occurring when the diaphragm was deflected to the snap point, and provision was made for this air to travel freely around the edge of the metal diaphragm and equalize the internal pressure with that of the very small air space between the metal disk and the rubber diaphragm. The snap diaphragm, in the unfired position, at no point should contact the trigger mechanism until it had been operated beyond the snap point.

8.3.2 Fuze No. 66 [3] and No. 67 [1]

These devices differed from each other so slightly that they will be treated as a single fuze. They differed from the early designs described in Section 8.3.1 in that the M1 release mechanism was entirely abandoned and a new firing system was adopted in which the firing pin, at right angles to the bimetallic diaphragm, received directly the blow delivered by the snap of the diaphragm. Thus, the elaborate triggering system, necessary in the previously used longitudinal design, was entirely eliminated and the desirable features retained. Figure 3 illustrates the general features of both the final fuzes.

The No. 66 fuze was provided with a 9-45 lb diaphragm, whereas the No. 67 bore a 9-70 lb diaphragm of Type C Phosphor bronze. These figures mean that the disk would snap at a pressure of 9 lb per sq in. hydrostatic, and exert upon the firing pin 45 or 70 lb,

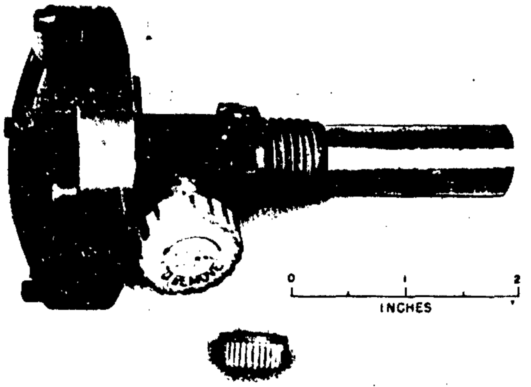

FIGURE 3. No. 67 Sympathetic Fuze.

which was sufficient to give high detonation. All parts were made of die castings, with the exception of the firing pin, positioning and catch springs, the snap diaphragm, and synthetic rubber parts.

Safety was provided by a salt block, which was located on the side of the trunk of the fuze. Dissolution of this caused a very lightly loaded positioning spring to displace a safety ball and to move the firing pin away from the snap diaphragm. When the firing pin had moved the proper distance, it was held in place by a catch spring fitting in a circumferential notch. This catch spring counteracted the force exerted by the positioning spring and placed the firing pin in an armed position ready to be struck by the snap diaphragm. When the end of the firing pin had moved from the snap diaphragm into the armed position, the diaphragm was free from any elastic deformation. Sufficient pressure on its outer convex face would cause it to deflect and snap into a dished concave position, thus delivering an impact directly against the firing pin, which, thus released from its catch spring, moved forward to fire the percussion cap. Actual photographic measurement showed that the time required for this snap operation varied between 500 and 2,000 microseconds. Figure 4[1] shows the details of the final design.

The fuze weighed 12½ oz, including a watertight cap screwed over the soluble plug and a second cap closing the striker channel. It looked like a mushroom measuring 2½ in. in height and 2⅝ in. in outside diameter. It was packed in hermetically sealed tear-strip tins 4 in. high and 3⅜ in. in diameter, the total weight being 1 lb 2 oz, including the detonator and burster.[7]

8.3.3 Depth Compensation[12, 13]

The design described in Section 8.3.2 is not compensated for depth and the Concussion Detonator may be expected to fire spontaneously when immersed to a depth sufficient to snap the diaphragm. In actual tests it was found that 20 ft was a safe limit for the 9-lb disk. Some work on a method of compensating such a fuze for depth was performed, but advantage was never taken of this because the complexity and added expense were not considered justified for the operations visualized by the interested Services.

The simplest and most effective method of obtaining compensation would consist of merely trapping a volume of air behind the snap diaphragm. For example, a short, vertical, open-ended pipe with the diaphragm sealing its upper end, would provide nearly perfect compensation for a fuze in a vertical position. Operationally, the variable volume of air backing would have to be sealed or so arranged that it could not escape in any position of the unit, which

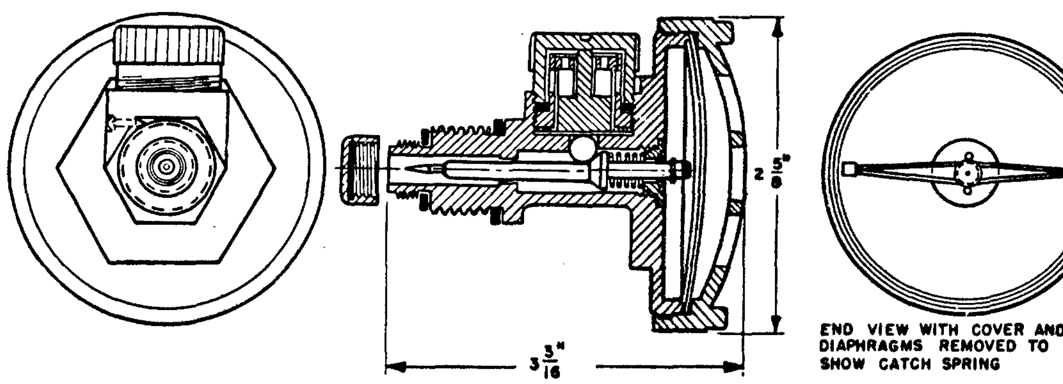

FIGURE 4. Cross-sectional and end views of No. 67 Sympathetic Fuze.

would not be true of the above system. Sealing off with a thin rubber membrane would be a possible solution.

Another possible compensator, a few models of which actually were constructed, involved the use of metallic bellows, which permanently soldered in place, offered no sealing, aging, or porosity problems. Such bellows, having 14 corrugations and a diameter of 2 7/16 in., were sufficient to compensate fuzes such as the No. 66 and the No. 67 to depths of approximately 50 ft. However, this compensation involved increased size and it was not regarded favorably. Also, because of cushioning or back pressure, the sensitivity of the diaphragm to the concussion wave might prove critical. For reasons such as these, compensation was not further investigated, but a number of reports [12, 13, 15, 18, 24] give full details.

8.4 ARMING

8.4.1 Salt Blocks

The use of salt blocks for the delayed arming of marine devices is very old, and a cursory study of available naval information indicated a great many varieties of salt blocks designed to give various timings. The principle of operation, of course, depends upon the dissolution of the salt block in water to the point where the device is armed and ready to fire. In the case of the Concussion Detonator, it was not necessary that the device be fully armed before this point was reached, for the concussion wave traveling through the water may exert a force upon the metallic click diaphragm sufficient to cause firing of the device if the salt block has become weakened.

The timing of the blocks used in the Concussion Detonators was the subject of many exhaustive studies by the Corps of Engineers,[3, 5] by Maryland Research Laboratories,[10, 21] and by the developer of the fuzes.[20] The Engineers conducted tests using actual salt blocks, in surf, in relatively still water, and in turbulent water at varying depths. The Maryland Research Laboratories and the Holmes Electric Protective Company conducted tests in a tank under controlled conditions of temperature and circulation. All data agreed that turbulence of the ambient water could seriously affect the arming period and that abnormal and undesirably short, safe arming times were obtained for fuzes in flowing water. For example, in water at 60 F flowing at the rate of only one knot, the safe time was reduced from 25 to 5 min, and the arming time from 1 hour to 25 min. Such behavior was independent of the nature of the salt plug and, generally, the addition of different salts and compression to different degrees did not influence this behavior. The effects of temperature, salinity, or position were minor.

The block finally selected for use was composed of 93.75 per cent sodium chloride, 6.00 per cent aspirin, and 0.25 per cent Prussian blue. It was molded under a total pressure of 2.17 tons. Attempts to rectify sensitivity to turbulence by alterations in the housing of the salt plug [10] were unsuccessful and no advantage was taken of them because of the lateness in the war of the development. It would appear that, if the Sympathetic Fuze is to be produced in the future, the salt block should be replaced by the Electrolytic Arming Disk, described in Section 8.4.2.

8.4.2 Electrolytic Arming Disk

This was intended for use in sea water and it would not operate satisfactorily in fresh water. Designed to utilize anode corrosion as a timing mechanism, it consisted of a disk-shaped primary cell mounted in a casing in contact with a spring-activated plunger in such a manner that the disk blocked the forward motion of the plunger. Its dimensions allowed it to be used as a replacement for the salt block in either the No. 66 or No. 67 model of the fuze.

In essence the Electrolytic Arming Disk was similar to the sea cell mentioned in Section 8.2.3. The primary cell consisted of a perforated magnesium disk anode electrically short-circuited at its center to a silver-coated silver chloride disk of smaller diameter which formed the cathode. Upon immersion in an electrolyte, such as sea water, cell action caused the magnesium disk to corrode. Corrosion was confined to narrow annular rings around the spokes of the disk, by masking the remainder of the surface with enamel or lacquer. When the spokes corroded, the center portion of the disk was ejected by the spring, and the plunger moved forward to actuate the arming mechanism. Typical data for the performance of such a disk are given in Table 2.[23]

Table 2 shows the negligible effects of temperature, position of the cell, and water turbulence upon timing. It was this last feature which so recommended the Electrolytic Arming Disk. Unfortunately, however, it was sensitive to salinity, as well as to the thickness of the disk and the amount of exposed surface, but

TABLE 2. Performance of Electrolytic Arming Disk.

Temperature degrees F	Position of cell	Time of opening in artificial sea water
50.0 ± 0.5	up	21.4 minutes
	down	23.9 "
	side	21.5 "
	Avg	22.3 "
70.0 ± 0.5	up	18.7 minutes
	up*	17.9 "
	down	19.8 "
	side	15.4 "
	side*	15.4 "
	Avg	17.4 "
90.0 ± 0.5	up	15.4 minutes
	down	13.7 "
	side	13.7 "
	Avg	14.3 "

* Cell kept in motion to simulate wave motion. All others in still water.

none of these objections were considered insuperable. The change in salinity was not considered serious for conditions likely to be encountered in the ocean or along its shores, and the other objections could be controlled in manufacture. Table 3[32] shows how the time obtained varied with salinity.

TABLE 3. Variations of time with variations of salinity.

Per cent normal sea water	Time of arming at 70F	Position of cell
114	15.0 minutes	up
	14.5 "	side
100	15.1 "	up or side
75	20.2 "	up
	19.9 "	side
50	28.2 "	up
	28.8 "	side
25	55.0 "	up
	50.3 "	side
0	12 hours	up
	11 "	side

Figure 5 shows views of an assembled disk and its component parts. Because the cell was sensitive to moisture, it was kept tightly sealed, until the moment of use, by a brass cap which was unscrewed when the Sympathetic Fuze was placed. Subject to the limitation of deterioration caused by atmospheric corrosion, the Electrolytic Arming Disk seemed to be a significant improvement over the conventional salt block. It could be made, of course, for any desired timing.

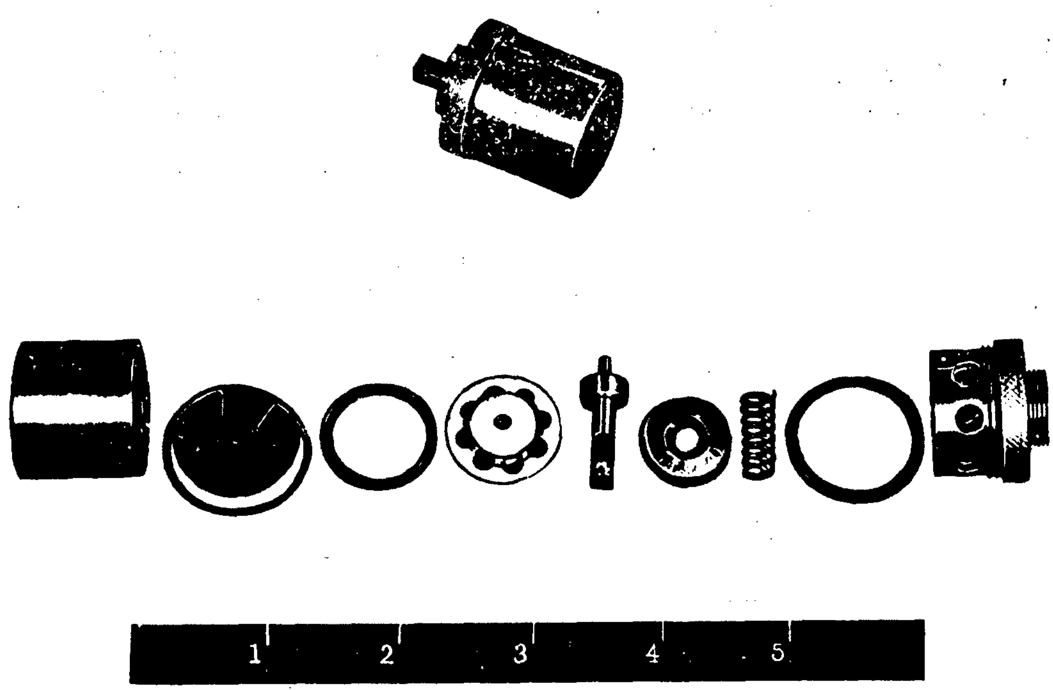

FIGURE 5. Assembled and exploded view of Electrolytic Arming Disk.

8.4.3 Silicone Arming Device [8] for Air Operation

For air use, neither the salt block nor the Electrolytic Arming Disk would suffice, because both required water for their performance. Work on an arming mechanism suitable for air operation was undertaken, since many devices could profit by such a development. The result was a dash-pot type of delay suitable for use with the No. 66 or No. 67 Sympathetic Fuze. It consisted of a piston pushed by a spring against a neoprene cup. The cup contained a silicone fluid which leaked through a capillary on the top of the device. With a suitably sized orifice, 10 min were required for the piston to move sufficiently to free the ball in the Sympathetic Fuze, thus arming it. The remarkable new silicone oils seemed especially suitable, because of the independence of their viscosity to temperature. Careful control of spring tension and orifice size would be required in manufacture.

There was a possibility that a volatile plug might be found which would function in air in a manner analogous to the salt plug in water. A search of chemical literature and appeals to a number of industrial laboratories failed to locate any substance which could be useful for this purpose, available in quantity, inexpensive, sufficiently volatile, and odorless.

8.5 PERFORMANCE IN WATER

Because of the incompressibility of water, the pressure wave set up by the explosion of underwater charges is large and extends over a considerable distance. Fortunately it was not necessary to determine the exact relationship between weight of explosive, pressure wave, time, and distance, for this had already been done.[4] From data of this sort, it seemed that the Sympathetic Fuze could be counted upon for reliable actuation by charges as small as 2½ lb at distances of 50 to 100 ft. Larger charges at greater distances could also be expected to give reliable functioning.

A number of tests conducted by the Engineer Board [3] and confirmed by other investigators [6] showed clearly that the range obtainable was a function of the weight of charge, the loading of the click diaphragm, and the type of bottom. It appeared to be independent of the type of high explosive used, no noticeable difference being obtained from charges of Composition C2, TNT, or Torpex. As might have been expected, the range was increased by increasing the depth of both charge and fuze, for the charge did not then expend any considerable portion of its energy in the air or against the bottom, as it would in shallow water, and the fuze was close to its spontaneous firing point because of hydrostatic pressure. It was found that the safe effective range for 100 per cent functioning, using a 9–70 lb bimetallic diaphragm, was 75 ft at a depth of 3 ft, and 100 ft at a depth of 5 ft. In all cases, standard charges of 2½ lb of high explosive were employed. The safe effective range was obtained over a mud bottom, and it could be expected to be doubled over a hard, sandy sea bed. Data of the sort usually obtained are given in Tables 4 and 5. Table 4 [3] indicates the relationship between range and depth of water using a 2½-lb charge with both charge and fuze at the same depth. Table 5 [6] indicates the difference between mud bottom and sand bottom with charge and fuze located at various depths using 9-70 lb diaphragms and a total water depth of 20 ft.

TABLE 4. Relationship between range and depth of water.

Depth of water in feet	Range in feet
2	40
4	90
8	200

TABLE 5. Variation between mud bottom and sand bottom.

Depth of charge and fuze in feet	100% firing distance of fuze from charge in feet: Mud bottom	Sand bottom
2½	55	105
3	75	125
4	90	165
5	115	200

The above tables have assumed that the Concussion Detonator and the actuating charge were at identical depths. Figure 6 [1] indicates the beneficial effect of increasing the depth of the actuating charge, regardless of the depth at which the Concussion Detonator is located. It is believed that this is instructive for many types of marine use.

The proximity of large objects which might tend to absorb the concussion wave, as would be expected, materially reduced the range, thus, for example, fixing the Concussion Detonator to a charge adjacent to a vessel resulted in appreciable loss in range and

sensitivity. In this case, the vessel could be considered as a large volume of air tending to cushion the shock wave. For work against underwater obstacles this consideration was usually unimportant.[19]

8.6 PERFORMANCE IN AIR

8.6.1 Metallic Diaphragm Type [9]

Table 1 indicates that fuzes of the No. 66 and No. 67 type could be used for the detonation of charges in air utilizing the shock wave produced in that medium. Because air is tremendously more compressible than water, such shock waves can be expected to have the necessary force only over much shorter ranges, and hence operation of the marine type fuze in this way, while possible, cannot be expected to equal the ranges shown in Table 5. Results obtained when plastic explosive or TNT was detonated in air in an open grass-free field with the metal diaphragm facing the sky are given in Table 6.

TABLE 6. Response range of Sympathetic Fuze in air. [9]

Actuating charge	Response range in feet
½ lb TNT	28
1 lb TNT	34
2 lb TNT	37
½ lb C3	27
1⅛ lb C3	33
2¼ lb C3	50
4½ lb C3	60
9 lb C3	75

From this data it appears that there was little difference in the effectiveness of the two explosives tested and that the effective operating range was not greatly increased by increasing the actuating charge. In special cases for short range work, particularly within confined structures where there are few obstacles separating the actuating charge from the Concussion Detonator, the latter may be useful, and the cumbersome and time consuming procedure of hooking together multiple charges with Primacord may be avoided. If this type of operation were an important one, it would appear that the development of a new fuze for the purpose would be preferable. Such a fuze in a preliminary form was devised and is described in the following section.

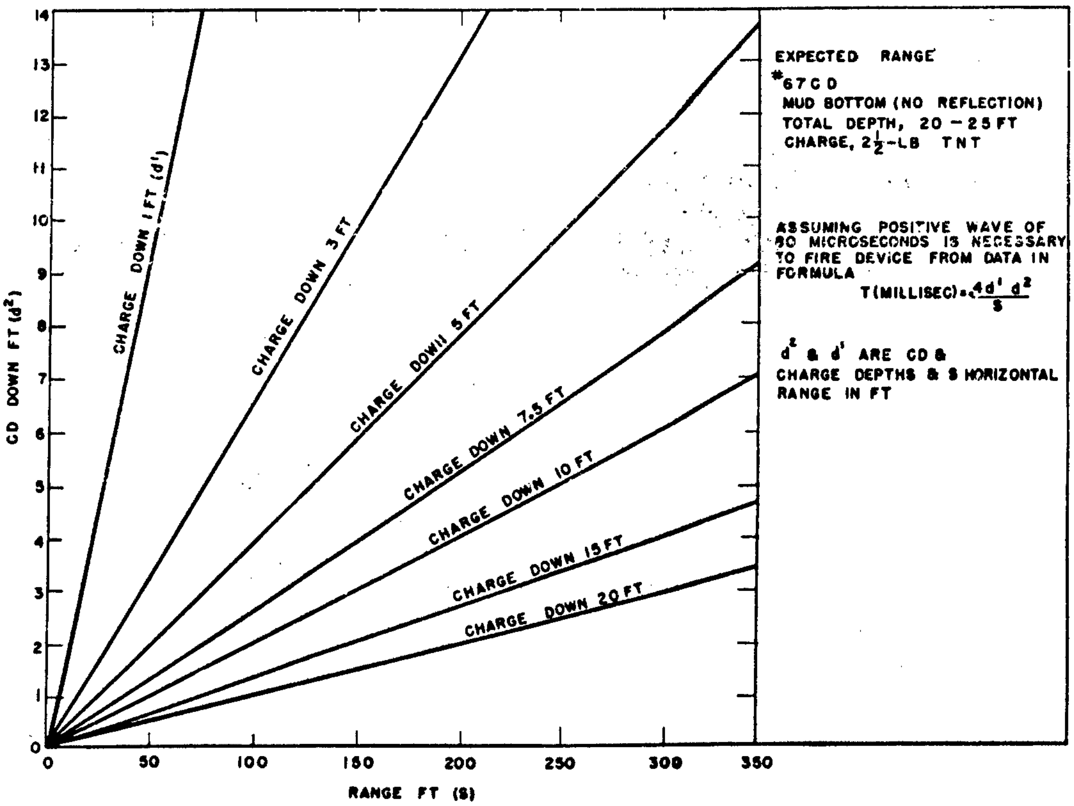

FIGURE 6. Effective range of No. 67 Sympathetic Fuze at varying depths of both fuze and actuating charge.

FIGURE 7. Operation of Sympathetic Fuzes in open water.

8.6.2 Reed Type [9]

Assuming that the use of batteries was allowed, a device was constructed which depended upon the closure of an electric circuit, containing a squib or electric blasting cap, by the action of the concussion wave from an actuating charge. It consisted simply of a reed connected to one terminal of a flashlight cell. Connection of the other cell terminal to a binding post on a contact plate was through an electric detonator to the reed clamp. An inward deflection of $^3/_{16}$ in. caused the reed to touch the sloping contact plate, and, because of friction, to adhere to it long enough for an intense electric impulse to pass through the squib. The sensitivity of this type of Sympathetic Fuze was found to depend on the stiffness and length of reed, the clearance between the edges of the reed and the edges of the opening in the fuze, the shape of the contact plate, clearance between it and the reed, and lastly the free volume of the fuze body and sound absorbing properties of its interior. Either hard beryllium-copper foil or similar aluminum foil of 0.006-in. thickness in a free length of 2 in. formed a suitable reed. Its separation from the contact plate was close to 0.005 in., the latter being at a constant slope of approximately 10 degrees. It was upon these features that the sensitivity of the fuze depended. Such a fuze seemed to respond to the relationship $R \sim Q^{1/3}$, where R is the operating distance when charge Q is detonated. Using the same actuating charges given in Table 6, the reed type under identical conditions gave ranges of 40 ft, 60 ft, 75 ft; 50 ft, 60 ft, 75 ft; 120 ft, and 150 ft,[9] averaging nearly twice that of the metal diaphragm type.

8.7 MANUFACTURE AND QUALITY [1, 2, 7]

NDRC semi-production, together with independent Engineer Board production on a larger scale, showed that the Sympathetic Fuze in either model No. 66 or No. 67 was feasible to manufacture. Die castings were used throughout with the exception of the firing pin, positioning, and catch springs, the snap diaphragm, and synthetic rubber parts. Tolerances were determined by many tests to be well within good manufacturing practice. No difficulty was encountered in obtaining uniform metallic diaphragms, and the chief trouble which arose was caused by the variability of the arming time when salt blocks were used.

Chapter 9

PENCIL (SRA-3) FIRING DEVICE, DELAY TYPE, M-1

9.1 INTRODUCTION [1,30,46,56]

In Part I of this volume, frequent reference has been made to the use of time Pencils for delayed-action firing of several devices including the rocket launcher (Chapter 1), the oil slick igniter (Chapter 2), the Spigot Mortar (Chapter 5), and special remote-firing devices (Chapter 7). The general usefulness of short and reliable time delays in clandestine and special operations is, therefore, apparent and does not require amplification here.

In most of the cases mentioned above, the time delay was employed to initiate an explosive charge or weapon and, in the form suitable for this purpose, was known in the United States as the Signal Relay American Model 3 (SRA-3). The British originators of the device had given it the code name Signal Relay. When it was put into American production, the distinction was made between SR and SRA, and, since American production went through several changes, SRA-3 represents the third and final model, 12,000,000 of which were ultimately manufactured. In the case of the oil slick igniter, the time Pencil was slightly modified to accomplish the initiation of an incendiary charge rather than an explosive charge. This was done by substituting a matchhead ending in place of the primer cap ending of the standard SRA and is the subject of Chapter 11.

A device, of such general usefulness was required in such a quantity as to warrant tremendous production, and a careful study of all factors which might affect the performance of the individual device and the reproducibility of batches of devices was necessary. This investigation was undertaken by Division 19 and two contracts were primarily concerned with many minor points for manufacturing, developing a number of alternative parts, and large-scale testing of the final products under carefully controlled conditions. The division cooperated for nearly two years with the interested Services (the OSS, their British liaison officers, and the Corps of Engineers) and with the manufacturers, so that the quality of SRA-3 steadily improved and the device, as finally produced, was nearly perfect for the given system. As will be clear below this system was inherently weak in that it depended upon complicated electrochemical and chemical reactions and by nature was greatly affected by temperature change and subject to the most unpredictable variations due to apparently minor changes in manufacturing procedure.

Sections 9.3 through 9.10 of this chapter analyze the different parts of the Pencil and the discoveries made with reference to them, while Section 9.11 indicates the test procedures developed for accurately determining the quality of production. The ultimate performance to be expected of the device is given in Section 9.12.

As a time delay, the SRA-3 covered the period between approximately 10 min and 11.5 hours at an ambient temperature of 70 F. This range of timing was achieved through the use of six models having nominal values, judged convenient for field usage. The limitations of reproducibility and temperature coefficient, however, tended to vitiate this system, so that a man in the field was required to use very good judgment in selecting a particular model for a given operation under given ambient conditions.

This stimulated, on the part of Division 19, a search for an improved system on which to base a Pencil time delay, and resulted in the so-called Mark II Pencil which is the subject of Chapter 10. It is believed that this development, while successful in producing a Pencil superior to the Mark I (SRA-3) in reproducibility and temperature coefficient, would, in practice, not supplant the Mark I for ordinary field use because of expense and positional requirements. Hence, the importance of this chapter in recording the numerous points discovered by the division's research into the Mark I Pencil. It is not believed that, should the Services require a time delay having simplicity, cheapness, and reliability, any great improvement could be made over the SRA-3 as finally produced.

9.2 DESCRIPTION AND OPERATION [1,52]

Two models of the Pencil were manufactured during World War II by the OSS and the Corps of Engineers. First production by the latter group was essentially complete prior to the work of the division and was comparable with the SRA-1, produced by OSS and soon supplanted by SRA-2 and SRA-3. The final production by the Corps of Engineers was comparable with the SRA-3. The basic difference between the SRA-3, which was the product of the OSS, and the firing device, delay type, M-1 of the Corps

of Engineers was in the ending, which consisted of a primer cap with spring snout, in the first case, and a standard waterproof primer and detonator assembly, in the second. These two devices will be treated as one and the description which follows is of the final SRA-3 production.

The Pencil was of the simplest construction. It consisted of a striker held against a compressed spring by a tinned iron music wire loaded under tension. This wire passed through a chamber containing a glass ampule filled with a copper chloride solution. Manual crushing of this ampule was possible, since the chamber was constructed of a thin copper tube. Upon being crushed, the ampule liberated its contents, which were absorbed in cotton wads, or wicks, located at either end of the chamber in close contact with the iron wire. A reaction was thereupon initiated which resulted in the erosion of the iron wire. In time, the strained wire would reach the breaking point, whereupon the striker would be forced forward by the compressed spring against the primer, initiating it and, hence, an explosive charge through the conventional detonator system. Figure 1 illustrates the SRA-3 in cross-section. The various components and their interrelation are made clear.

Reference to this figure shows a number of parts which received particular attention in the research work of the division. These parts are the tension wire, the ampule solutions, the wicks, the reaction chamber, the spring, the primer, and the plunger. Each of these is discussed in a section below. The other parts not mentioned appeared to have no unpredictable effects upon the performance of the Pencil and, hence, are not discussed here. Their specifications could apparently not be improved upon.

The timings provided by different models of the SRA-3 resulted when different solutions were placed in the glass ampule. These solutions, for convenience, were given names based on primary colors, and the different models of the Pencil were distinguished from one another by the corresponding color of the safety strip, thus the six models of the SRA-3 were known as Black, Red, White, Green, Yellow, and Blue, in order of increasing time from 10 min to 11.5 hours. Exact timings for various temperatures will be found in Section 9.12.

In field use OSS specified that two Pencils should be employed for any given operation, and this procedure was strongly urged for the Corps of Engineers. From a statistical viewpoint, the use of two Pencils gave a reliable and predictable timing, and the figures quoted in time-temperature charts prepared by Division 19 were based on this usage. When possible, therefore, an individual employing time delay Pencils would connect two of them to the device or charge to be initiated, and, with the safety strips still in place, manually crush the reaction chambers containing the ampules. The safety strips then would be removed and a quick departure made. In this way, the occasional premature, which might be encountered on crushing the reaction chamber, was rendered harmless.

9.3 TENSION WIRE

9.3.1 Substitutes for Music Wire[2,7,27]

When the specifications for the SR were received from England and applied to American production, every attempt was made to duplicate in this country the exact details of the British device. One of the most difficult parts of the SRA to copy was the tension wire, a hardened 14-mil iron music wire having a

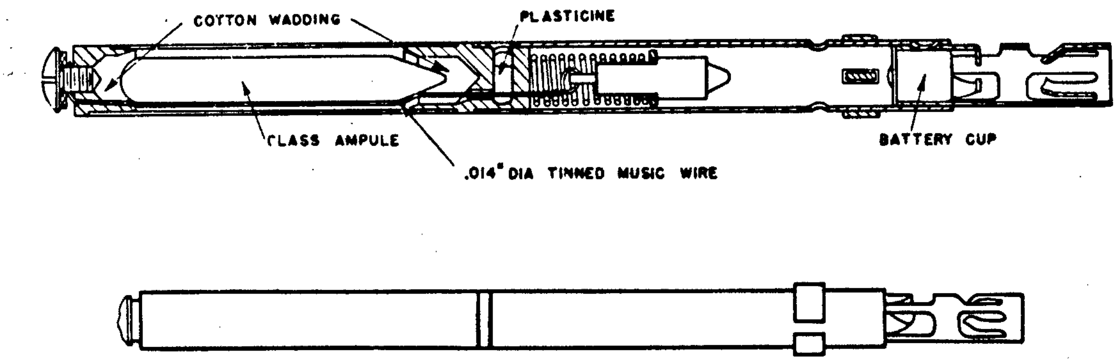

FIGURE 1. Cut-away view of SRA-3, actual size exterior.

protecting tin coating. In the SRA-3, the diameter of the wire was changed to 20 mils, but otherwise it remained unaltered throughout the war, although considerable work was done by the division to find an improved steel wire and an improved procedure for protecting it. Both nichrome and stainless steel wire had very high mean deviations and therefore were not considered further.[6] More encouraging results were obtained with a softer and thicker (42 mil) wire, and very encouraging results with standard 20-mil wire when coated by hot dipped galvanizing (see Section 9.3.4). No experiments were performed to show the exact relationship between operational time and chemical composition of various wires. Further study along these lines might be profitable, since it was found difficult in practice to obtain from wire manufacturers uniform coils having an elemental analysis which could be reproduced from one to another. The effect of these minor elemental variations was never explored.

9.3.2 Tensile Strength [4,7]

A study of the variation in tensile strength of the wire used in production, both between coils and within coils, yielded no significant result in the case of the electrogalvanized wire, ultimately recommended, but did indicate a significant difference in the case of the tinned music wire used in production. For example, the variation in average breaking strength along a coil of 14-mil production wire might be: 62.1 lb at one end, 61.3 lb in the middle, and 59.8 lb at the other end. Further data would have to be obtained before it could be said that this variation was significant, but it appeared to investigators that it might be. Thus, further work would be indicated, if the tinned music wire originally specified were to be used in future production.

The ultimate tensile strength of such wire was 391,000 lb per sq in., in contrast to the value of 102,000 lb per sq in. obtained with 30-mil electrogalvanized low-carbon steel wire recommended by the division. Whether a high or low tensile strength wire was preferable is still a moot question.

9.3.3 Internal Structure

In the hope that variations within and between coils of production wire might be detected by simple analytical procedures, the microstructure of the tinned music wire was examined.[14] The results were entirely negative. No correlation appeared to exist between microstructure and performance, since the crystal grains were so seriously distorted.

9.3.4 Surface Treatments [24, 25, 26, 29]

As already stated, the original specifications called for a tinned music wire but the use of tin for the purpose of protecting iron wire was repeatedly questioned on sound scientific grounds by the division. It is well known that, in all common media, iron is anodic with respect to tin and hence the tin, unless it forms a perfect coating over the iron wire without pinholes, will actually facilitate its erosion by the atmospheric conditions of storage. That this was a very serious problem in the field became apparent when it was learned that tremendous stores of the original British production had shown over 50 per cent failure after one year's storage in the humid, tropic conditions of India. The work of the division clearly showed that much better protection for iron wire was provided by a thinner coat of electrogalvanized zinc, and the recommendation for a change from tinned wire to zinc-coated wire was eventually accepted and written into the specifications. However, prior to the use of this improved wire, production ceased because of the ending of the war.

Application of zinc by hot dipping, the procedure used for tinning, was definitely inferior. The maximum thickness of zinc that could be used with the specified solutions of all colors without causing secondary difficulties was $1.6 \times 10^{-}$ in., a figure which was easily obtained by a simple laboratory procedure. Coils of wire thus protected were made for experimental purposes and were used in the subsequent development of the Mark II Pencil (see Chapter 10). It was also shown that, for uniform performance in the Pencil, the tension wire should be either completely free of grease or covered with a continuous oil film.[24]

A number of other treatments, including beeswax coating, Parkerizing, and protective oxidation, were all inferior to electrogalvanizing. It is interesting that in a Russian time Pencil, which was provided for analysis, a 16-mil bare spring wiring had no coating whatsoever. It was the opinion of the research workers in the division that this was preferable to the tin wire specified by the American Services but inferior to the electrogalvanized wire eventually recommended.

9.3.5 Wire Variations [3, 23]

It was clearly demonstrated that commercially obtainable tinned music wire, as delivered to the Pencil manufacturers in 4-lb coils, showed considerable variation both within and between coils. Whether this was caused by the inevitable variation in tinning or was inherent in the wire was difficult to say. At any rate, it represented a serious hazard to reproducibility and eventually necessitated testing each coil in the completely assembled Pencil before that coil could be used for production. Apparently, this could be corrected by electrogalvanizing treatment, and, should production of such a device be undertaken in the future in more than one country or locality, all manufacturers should be provided with wire from a single commercial source. Every attempt to secure a wire identical with British wire, from American manufacturers, resulted in failure, and the British themselves were unable to reproduce the wire previously used.

9.4 SOLUTIONS

9.4.1 Solution Analysis

ABSOLUTE CHEMICAL ANALYSIS [33, 37]

As part of the original British specifications, a chemical method was provided for the manufacturer to prepare the ampule solutions to the tolerances specified and determined essential for reproducible Pencil functioning at given times. For the Black and Red Pencils having normal timings of 10 and 20 min at 70 F, no difficulty was encountered because the ampule solutions contained only water and hydrated cupric chloride of analytical quality. The other four colors, however, contained a third component, namely, glycerol. This was added to increase the viscosity and to reduce the rate of chemical reaction, and thus to provide longer timings. Table 1 [26] gives the exact compositions specified for the different colors.

The absolute chemical determination of the percentage of glycerin and of copper in a solution prepared for these colors was extremely difficult. Following the original British directions, variable results were obtained in different laboratories in this country. This necessitated a study of the method, for the performance of the Pencils was based entirely on an accurate knowledge of the composition of the ampule solution. Eventually, a satisfactory procedure was devised depending upon the determination of the cupric ion by titration with sodium thiosulfate, followed by long digestion of the solution with an excess of potassium dichromate, and by titration of the remaining oxidants (unused dichromate and cupric ion). A simple calculation thereupon provided the original composition of the solution in terms of glycerol and copper chloride. These manipulations required so much analytical skill and expenditure of time as to be of little value to the ordinary manufacturer, and a more convenient and accurate analytical procedure was necessary. Two such procedures were devised and are described in the following two sections. Both of them had accuracy equal to or superior to the absolute chemical determination and were preferable in all other respects.

TABLE 1. Composition of various colors of Mark I Pencils.

Color	% $CuCl_2 \cdot 2H_2O$	% Glycerol	% Water
Black	13.86	...	86.14
Red	37.76	...	62.24
White	10.38	48.8	40.8
Green	35.05	38.2	26.7
Yellow	33.15	46.1	20.7
Blue	10.13	72.2	17.7
Revised Green*	24.95	47.3	27.5
Revised Yellow*	22.70	55.7	21.6

* These compositions were deduced as a result of the study mentioned in Section 9.4.6 and would be expected to give improved performance regarding reproducibility and temperature coefficient.

SPECIFIC GRAVITY AND GLYCEROL CONTENT [10, 13, 17, 19, 31]

Both British investigators and the division's research laboratories did considerable work with a system of analysis based upon determination of the percentage of copper chloride by the thiosulfate titration already mentioned and by specific gravity. Determination of the specific gravity of a solution was a simple, accurate, and quick procedure. Two reports were issued by the division's contractor [10, 13] which showed clearly that the procedure was suitable for the use by manufacturers, with the result that it became part of the specifications as written by OSS and the Corps of Engineers.

The White and Blue solutions, which contained nearly 10 per cent copper chloride hydrate, were found to fit an empirical equation as follows: specific gravity (25 C/25 C) = 0.9747 + 0.0100 (% $CuCl_2 \cdot 2H_2O$) + 0.0284 (% glycerol). Table 2 [10] shows the accuracy of the method.

TABLE 2. Relationship between specific gravity and glycerol content.

Specific gravity 25C/25C	% $CuCl_2 \cdot 2H_2O$	% Glycerol dichromate method	% Glycerol empirical equation
1.2086	9.52	48.9	48.83
1.2807	9.52	74.0	74.23
1.2278	9.74	54.7	54.82
1.2262	10.26	52.7	52.43
1.2664	10.23	66.7	66.69
1.2343	10.77	53.5	53.49

A family of curves was determined experimentally which fitted the above equation within the limits of error of the experiment. The data was presented in charts relating the specific gravity to the percentage of glycerol for varying concentrations of copper chloride, and the specific gravity to the percentage of copper chloride for varying percentages of glycerol. Similar curves were determined for the Green and Yellow solutions in which the percentage of copper chloride was between 32 and 37. Unfortunately, in these higher concentrations no empirical relationship expressable by an equation could be discovered. It was clear that the curves were not parallel, as in the earlier case, and that they were not linear. Nevertheless, the charts were sufficiently useful to be included in the specifications.

So that this data might be more useful to manufacturers, solutions prepared by weight and carefully checked by absolute chemical analysis were then compared with the specific gravity data already mentioned, and acceptance area charts were drawn for each of the solutions relating specific gravity to percentage of copper chloride. It was only necessary for the manufacturer to prepare a solution as accurately as possible by weight, then to determine its copper content and specific gravity, and by the use of acceptance chart to find whether the resulting point lay within the area specified. Eventually producers in both Britain and the United States used this procedure.[19]

A sample chart for White solutions appears as Figure 2.

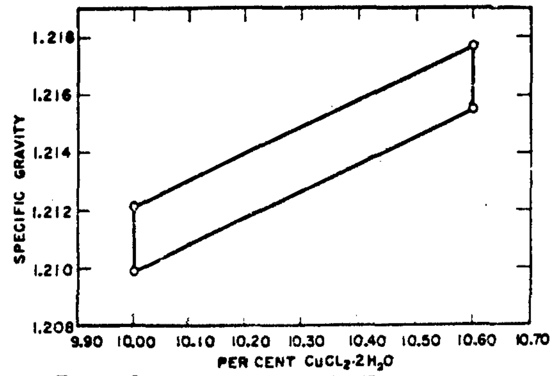

FIGURE 2. Acceptance chart for White solution.

REFRACTIVE INDEX AND GLYCEROL CONTENT [35, 43]

A physical measurement, rivaling the determination of specific gravity in ease and exceeding it in speed, was the determination of the refractive index by the Abbé refractometer (see Table 3).

Application of this procedure to the four solutions containing glycerol showed clearly that the method was sufficiently precise and compared favorably with the specific gravity method in ease of operation, size of sample, and speed. Charts were prepared showing the relationship between the refractive index and the percentage of glycerol for solutions containing known percentages of copper chloride. Acceptance charts also were constructed. Unfortunately, the refractometric method was not put into use, largely because of the unavailability of suitable refractometers. In any future production, and certainly in any large research program, the refractive index method would probably be preferable to any of the other analytical procedures.

TABLE 3.* Analysis of per cent glycerol by refractometry.

Color range	% Glycerol by synthesis	% Glycerol by refractive analysis	Refractive index
Blue	75.1	75.1	1.4603
Blue	73.05	73.55	1.4582
Yellow	32.95	33.75	1.4512
Yellow	41.3	42.1	1.4656
Green	46.9	47.3	1.4746
White	52.55	53.1	1.4263
White	50.8	51.3	1.4235

CONDUCTOMETRIC ANALYSIS [53]

British work on a further analytical basis compared the resistance of solutions at 1,000 cycles in a special cell with that of permanent standards. As in the three previous methods of analysis, the conductance was used with an iodometric thiosulfate determination of copper. Analysis for the percentage of glycerol was thereby possible. The specific conductivity was measured in a bath thermostatically controlled to a temperature of 25.0 ± 0.2 C and it appeared that the control of temperature of the solution was the limiting factor in the usefulness of the

method. The solutions containing glycerol, having a very high viscosity, did not reach a constant temperature in a reasonable length of time; and, because of the variation in conductance per degree C was approximately 5 per cent, the method was criticized on the basis of practicability, especially in view of the ease and simplicity of the specific gravity and refractive index procedures already mentioned. As in the other cases, acceptance area charts and graphs relating conductance to percentage of glycerol for a constant percentage of copper chloride were prepared.

9.4.2 Optimum Volume [8,9]

In the early days of SRA production, the importance of the volume of solution contained in a Pencil ampule was not appreciated. Moreover, manufacturers declared that the manufacturing difficulties of making ampules of the size required for the reaction chamber of the Pencil was a sufficiently difficult task without the added imposition of a complete, or nearly complete, filling. The SR production in Britain was based on an ampule containing somewhat less than 0.6 cc of solution; the volume of the early American products (SRA-1 and SRA-2) in many cases did not exceed 0.4 cc. It was not long before tests showed that this decrease in volume was having serious effects upon the reproducibility of the American product.

A study was thereupon undertaken in which the volume of the ampule solution was continuously varied between 0.3 and 0.8 cc. The data clearly showed that 0.7 cc should be the minimum volume of solution used in any case. With less than 0.7 cc, there were indications that two reactions occurred: first, the action of cupric ion on iron wire, and secondly, the action of cupric ion on copper forming cuprous ion, which in turn either precipitated or reacted with iron. Because the latter reaction was much slower than the former, for Pencils having a low ampule volume, an extensive period of time would be required for complete reaction. Moreover, the time required for the ampule solution to be soaked up by the wicks appeared to be a function of the volume. A study of Figure 3 clearly illustrates this point.

The recommendation to increase the ampule volume was accepted by the Services and, ultimately, by the manufacturers, and resulted in greatly improved performance of the SRA-3. It was interesting to note that the Russian time Pencil had a volume of 0.71 cc.

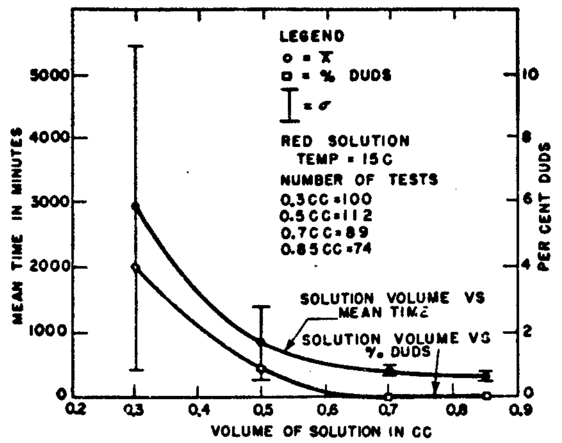

FIGURE 3. Effect of solution volume on timings.

9.4.3 Off-Color Solutions [16, 34]

The assembly of the Pencil by hand gave an opportunity for observing the real color of the ampule solutions as they were inserted. This should not be confused with the color of the ampule specified for a given time. Since all the solutions contained copper chloride in varying amounts, they were the characteristic blue-green color of that salt, except for the White ampules, which were so nearly colorless as to require the addition of a trace of organic dye for their detection.

Operators on the assembly line frequently observed that the real color of the solutions varied from one ampule to another in the same batch. Upon instruction, they removed these off-color ampules and these were subsequently submitted to analysis. Frequently ampules of this type whose shading was not constant showed gross variations from the specifications for either glycerin or copper chloride content. Therefore, the practice was established of discarding all such ampules. The source of the difficulty appeared to be in the ampule filling machines which, when started after a rest period, delivered variable concentrations for a short time.

In future production this point could be observed easily.

9.4.4 Diluents Other Than Glycerol

Because the determination of glycerol was so difficult (see Section 9.4.1), attempts were made to discover other chemicals which might replace glycerol and which, in addition, might give lower temperature coefficients to the resulting solutions. Investigations

of a number of water soluble alcohols, polyhydroxy alcohols, and sugars as substitutes for glycerol was undertaken but without success. The only significant discovery was that the replacement of glycerol by *n*-propyl alcohol [2] gave improved performance with Blue and Yellow timings.

Here a new difficulty arose in that the solution was too volatile for direct replacement. Methods of sealing the solution within the reaction chamber were devised but nothing beyond semi-production was ever undertaken.[6] Acetic acid, ammonium hydroxide, diethyleneglycol, ethyl lactate, ethyl acetate, and dioxane were tested without satisfactory results.

An attempt to increase the maximum timing of the SRA to 3½ days resulted in the development of a solution containing diethylenetriamine, but this solution proved so critical to the minutest change in concentration that it was discarded as unsatisfactory. Figure 4 clearly shows how minor variations in the percentage of copper chloride could cause tremendous variations in timing. This effect was observed occasionally in standard specified solutions also.

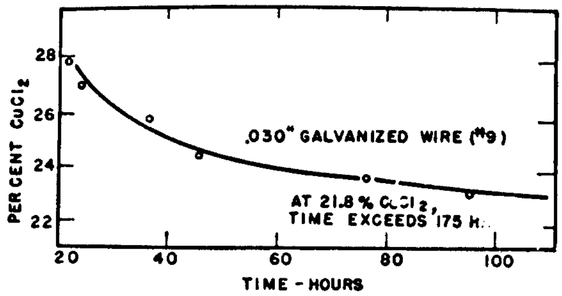

FIGURE 4. Effect of copper chloride content on firing time in solutions containing 30 per cent diethylenetriamine.

9.1.5 Addition of Foreign Substances

There was reason to think that the presence of hydrochloric acid was beneficial to the performance of the SRA. Full study, however, showed that this was not the case.[22] It was found that generally acidity had little effect on the variance, but did tend to increase the mean time. As a result, recommendations were given to the Services on the *p*H allowable for each color solution. These were incorporated in the manufacturing specifications as follows: Black, 2.0 to 2.5; Red, 1.0 to 2.0; White, 1.0 to 2.0; Green, 0.5 to 1.0; Yellow, 0.5 to 1.0; Blue, 0.7 to 1.7.

As already mentioned, White solutions, because of their colorless character, required staining by the addition of a trace of an organic dye, Scarlet Moo.[2] With the object of improving the temperature coefficient, experiments, designed to form copper complex ions, were performed with solutions varied by the addition of ferric chloride, sodium chloride, and magnesium chloride. The results did not warrant further investigation,[2] nor was the presence of a compound lowering the surface tension effective.

9.1.6 New Solutions [20, 21]

One entirely new solution providing a 3½-day delay has been mentioned. Other new solutions in which glycerol was replaced by raffinose, and copper chloride was replaced by ferric chloride, stannic chloride, or mercuric chloride were also unproductive, depending apparently upon the age of the solution and the area of the tension wire exposed. Two-phase systems were likewise unsuitable although British workers at Oxford were successful in devising one which had a remarkably low temperature coefficient.[55] More significant was the development of improved compositions involving only the original materials: copper chloride, water, and glycerol. Sufficient data were obtained to establish tables relating time to percentage of glycerol, and time to specific gravity for various copper chloride concentrations. From these, isochronic lines were drawn on charts relating copper chloride to percentage of glycerol, and copper chloride to specific gravity. From these plots, it was possible to obtain the composition and specific gravity of solutions having the least glycerol or copper chloride coefficient for any mean time in the range of a given color. A selection of the best composition of the three components was thereby possible and an ampule solution, showing optimum independence of temperature,[24] was provided.

From these charts, it was deduced that the specified compositions of Green and Yellow solutions were not at the optimum position, and revised compositions (see Table 1), having lower glycerol coefficients, were recommended.[25] The compositions for White and Blue solutions appeared to be, at least, satisfactory. Unfortunately, the recommendation was never put into practice because of its lateness. Should a production of the Mark I Pencil be undertaken in the future, other specifications for Yellow and Green solutions appear desirable.

9.5 WICKS

The action of the wick in the ampule chamber was to insure a constant supply of fresh corroding solu-

tion to the iron wire. Obviously, bad wicking would result in high deviation in time. The manufacturer's practice of using hand-formed pellets of cotton was demonstrated to be responsible for a certain amount of variation.[12] A study was undertaken of several fibers possible for the purpose, including surgical cotton, Kotex, fiberite. No great improvement over the use of chemically neutral cotton could be shown. However, it was found that preformed dental pellets of fairly uniform weight (14 milligrams) gave uniform performance and were considerably easier to use in the assembly line.[36,40] Incorporation of this minor change in the specifications would seem desirable.

9.6 REACTION CHAMBER

9.6.1 Sealing

The SRA-3 reaction chamber consisted of a thin crushable copper cylinder, a center plug of copper-plated brass, and a similar end plug. While not waterproof, the chamber was necessarily constructed to prevent leakage of the ampule solution after crushing. Sealing of the chamber was provided at the center plug by the use of Plasticine or molding clay, which was injected around the tension wire at the point where it passed through the center plug. Sealing at the end plug was obtained by passage of the tension wire through a very small hole, and firm pressure under a lead washer surrounding the anchoring screw on which the tension wire was wound. While the suitability of Plasticine and similar materials was demonstrated,[36] there was more question about the lead washer, which on occasion lubricated the tension wire allowing it to slip on long standing.[2] A recommendation that soldering be substituted for the screw procedure of anchoring was not acceptable to the manufacturers.

In the case of the volatile solutions containing n-propyl alcohol (see Section 9.4.4), complete closure was obtained by dipping the Pencil end in collodion solution. This was in line with the practice followed by the Russians, who dipped their Pencils in a high melting wax such as beeswax.[5] It would appear that the present method of sealing the reaction chamber was sufficiently good for the use of the Pencil above water, and, since the device was not suitable for use below water for other reasons, it would appear to have been adequately handled.

9.6.2 Materials

The crushable copper tube was annealed soft and provided with a slight flare at either end where it fitted over the end or center plugs. It was found that the manufacturers were brightening this tube by a series of acid and alkaline washes with the result that the tube as assembled in the Pencil had a distinct alkaline coating which interfered notably with the performance of the ampule solution.[15] Tests showed also that the end and center plugs, which were brazed, required a complete and smooth coating of copper plate in order to give resistance to the corrosive action of the ampule solutions. It seemed that the zinc contained in the brass plugs, if exposed to the solutions, would enter preferentially into reaction with them, thus altering the effective concentration of copper chloride and unpredictably affecting the timings.[8,9]

9.7 SPRINGS

The quality of springs gave trouble throughout the production of the SRA. Wire of a suitable resiliency was hard to obtain, and the specification of flat-ground ends was never met. This tended to throw the striker off center and occasionally resulted in misfires (see Section 9.9), but was, on the whole, not as serious as the variation in length among springs and the tendency of all springs to take permanent set[4] on standing. It was interesting to note that the Russian time Pencil spring had precision-ground ends.[5]

Manufacturing procedure at the start of American production called for the loading of the spring to position, and, since it was clearly shown that springs varied in length by a considerable factor, it was apparent that a variation in load was being obtained, which was found by actual tests to lie between 14 and 20 lb. This meant that the tension wire was under a variable tension, and hence wires in different Pencils would part at different times. A tightening up of the acceptance of this part served to correct this difficulty.[2]

Ultimately, a change-over from position loading to dead-weight loading in manufacture was achieved and the specification was rewritten so that the springs were loaded to 15 $\pm$ 1 lb, giving greatly improved performance. No solution was ever obtained to the problem of permanent set, which by experimentation was found to result in a variation of timing of about 3.4 per cent per lb of load change.[2,18,28,39]

9.8 PRIMERS FOR SRA-3'S

The OSS model of the Pencil utilized special primers, which upon request the division undertook to test to determine their behavior on prolonged immersion, accelerated aging, and exposure to conditions of high humidity and temperature. An unpredictable failure of approximately 0 to 2 per cent of the primers was obtained, and higher percentages on prolonged immersion. Very good stability to accelerated aging was noted.[38] In the SRA-3 the primer was crimped in tothe end of the Pencil flush with a steel spring snout which was of a size to receive Primacord or Bickford safety fuze. This feature was lacking in the Corps of Engineers firing device delay type M1, and no tests were performed by the division on the initiating system of that fuze.

9.9 PLUNGER

As already mentioned, the use of unground springs gave an eccentricity to the travel of the plunger which at first was not felt to be serious. The point was, however, investigated, and it was found[44, 45] that the primer caps in the SRA-3 had varying sensitivity, depending upon the location of the blow. With eccentric initiation, increasing failure could be expected as the primer struck further off center. Correction of this difficulty was easily achieved by a redesign of the plunger, which in the SRA had been made from brass rod by screw machine processes but which in the SR was made from square bar brass at slightly increased cost. The latter design allowed the plunger to rest on the walls of the brass striker tube which guided it to the primer insuring a central strike. A change in the SRA specifications completely corrected the difficulty.

The energy with which the primer was struck by the plunger was the function of the spring, as well as the friction encountered by the plunger in traveling through the brass tube. The energy imparted (67 oz-in.) to the striker by a spring at 15 ± 1 lb load was more than sufficient to give 100 per cent functioning with central or intermediate eccentric strike on the primer but to fail on extremely eccentric strike (requiring 111 oz-in.).

9.10 PACKAGING

Mention has already been made of the susceptibility of Pencils made with tinned wire to storage under conditions of high humidity. The numerous pinholes in the tin surface provided excellent opportunity for corrosion and weakening of the tension wire with the result that after two years of exposure fully 50 per cent of the stored Pencils would be found to have fired. Those which had not fired were obviously in a weakened condition and, hence, a danger. The problem of protecting the Pencil from this corrosion effect was a serious one which would have been met by the adoption of electrogalvanizing. Unfortunately, failure to accomplish this meant that another solution had to be forthcoming. This was obtained in the use of a packaging envelope for each individual Pencil.

The last considerable fraction of the OSS production was packaged in transparent tubes of polyvinyl chloride [PVC]. The very remarkable improvement in functional efficiency thereby obtained was clearly demonstrated in elaborate tropical weathering cycles. Strangely enough, unpacked Pencils behaved with equal efficiency. It was only when Pencils were packaged in tins that the severe loss of storage resulted. The explanation of this lay in the retention within the tin of ambient humidity and favoring of corrosion. In future production the packaging of Pencils individually in PVC or similar impervious containers would seem warranted.[49, 54]

9.11 TEST PROCEDURE

9.11.1 For Research

For several years the Division, through two major contracts, did a large amount of work on testing and improving the time Pencil. This work was correlated to some degree with similar activities in Britain and with test procedures in force at the Engineer Board at Fort Belvoir, Virginia. At the start, there was no agreement among these various groups, which were widely scattered geographically, as to the manner of conducting time tests or the manner of analyzing the results obtained. This lamentable situation was corrected[57] by the adoption of a set of conditions for tests and agreement on the statistical handling of the data. For the former, several temperatures were selected and thermostatic chambers provided so that the temperature variable could be controlled. In addition, agreement was achieved on the position which the Pencil should occupy while under test. This was accepted as horizontal, because it appeared to be the most logical position for field use. It was agreed that

in the horizontal position the Pencil should be mounted so that the tension wire which is unsymmetrically placed in the reaction chamber should be down. Crushing was accomplished in the horizontal plane by the use of especially designed pliers having jaws of a given area and stroke to provide entirely uniform crushing. No figures obtained from less than 50 test results were considered as entirely suitable for proof of any recommendation.

Figure 5 [11] is a sample of the presentation of such data in graphical form for a batch of 26 Yellow Pencils at 25 C. The number firing in any given time interval of 20 min is recorded. By the mode is meant that point in time at which the greatest number of Pencils fired; by the median is meant that point in time midway between the two extremes of the whole group; and by the mean is meant the arithmetic mean of all the timings.

Presentation of the data obtained was done both in tabular and graphical form, according to conventions adopted by the research groups.[57]

In Figure 6 is shown a rack with 10 Pencils of which half have been crushed and are ready for insertion into the thermostatically controlled chamber.

The importance of this procedure for handling research on time delays cannot be over-estimated. It was not until this procedure had been adopted that the maze of complexity of the Mark I Pencil could be penetrated. Should any further research be done, it is recommended that it be undertaken with the same or similar definitions and prescribed procedures.

Having set down the rules by which research would be conducted, it was interesting and profitable to learn how changes in these rules would affect operation of the Pencil. A study was therefore undertaken of the effect of orientation and method of crushing on timings obtained. This had, in addition, important field use, since, if some simple relationship could be found, the field could be instructed in the optimum usage of the Pencil. Considerable variations were found depending on whether the wire was up or down during the operation of the delay, on the direction in which the crushing took place, and on the extent of crushing, as well as on the plane in which the Pencil rested while operating.[41, 50]

It appeared as a generalization that Pencils commonly used in pairs and activated in the field led to timings of about 25 per cent shorter than those obtained under accepted testing conditions, with the shortest mean timings being obtained when the Pencil made an angle of 45 degrees with the horizontal.

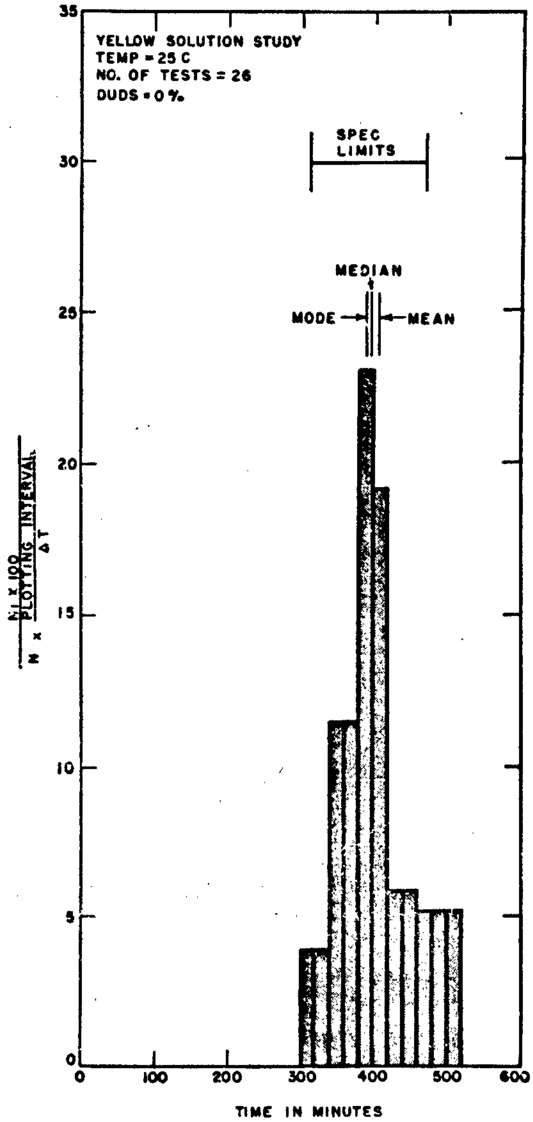

FIGURE 5. Sample timing chart of Yellow Mark I Pencil.

The extreme mean and maximum timings were obtained when the Pencil was tested vertically with the snout down. This most unfavorable of all positions was also the one least likely to be used in the field and, hence, was not considered serious. In fact, in any given operation, the variable method of crushing and placing of the time delay made exact prediction of the time at which the Pencil would operate a highly problematical matter. Nevertheless, the general value of tables, such as that given in Section 9.12, is not discredited.

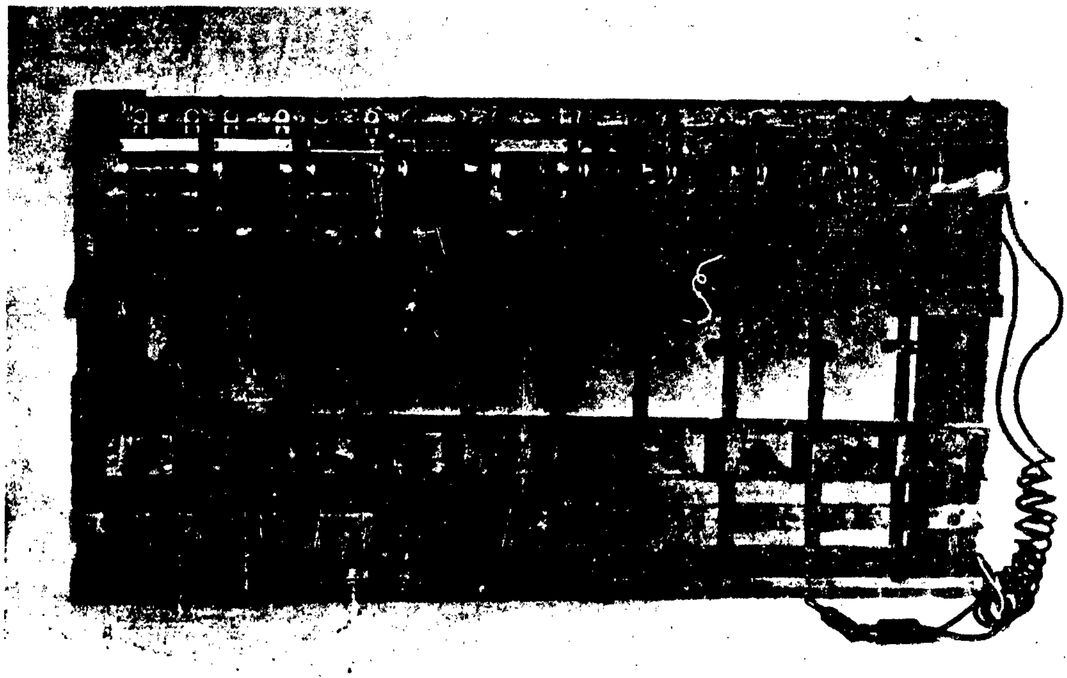

FIGURE 6. Timing rack for Mark I Pencil.

9.11.2 For Quality Control in Production [32, 42, 47]

Although production and quality control of it were not the function of Division 19, advice was given which ultimately assisted in a satisfactory method of batch analysis and which was capable of detecting trends in quality of the assembly lines prior to the point at which production would have been rejected. This necessitated a rigorous inspection procedure of production as it emerged from the factory, and it is to the credit of OSS that they and their British liaison officers insisted upon and obtained adequate testing facilities and personnel by which all production under their auspices met a very high standard of performance. The references noted contain the details of this system, which worked so well.

A complete analysis of American Pencil production for nearly one year [56] is interesting in this regard. From it, data may be quoted which indicate the parts of the Pencil against which the percentage of variance may be assigned. It appeared that the ultimate, which could be expected by the Mark I by careful quality control, was about 12 to 16 per cent for any individual sample, and the percentage of variance caused by wire variations averaged around 15.4,

TABLE 4. Chart of operational timings of SRA-3's.[61]

tC	tF	Black OM	Black ST	Red OM	Red ST	White OM	White ST	Green OM	Green ST	Yellow OM	Yellow ST	Blue OM	Blue ST
− 32	− 25	....	....	....	....	3 day	1.3 day	....	....	....	....	....	....
− 18	0	....	....	45 min	20 min	17.5 hr	8 hr	2.2 day	1.0 day	8.5 day	3.8 day	23 day	10 day
− 4	+ 25	36 min	16 min	25 min	11 min	5.5 hr	2.5 hr	19 hr	8.5 hr	2.0 day	20 hr	5.0 day	2.2 day
+ 10	50	15 min	7 min	17 min	8 min	2 hr	55 min	6.5 hr	3.0 hr	14 hr	6.0 hr	1.3 day	14 hr
24	75	9 min	4 min	15 min	7 min	1 hr	27 min	2.7 hr	70 min	5.5 hr	2.5 hr	11.5 hr	5 hr
38	100	5 min	2.0 min	8 min	3.5 min	32 min	14 min	72 min	30 min	2.5 hr	65 min	5.2 hr	2.3 hr
52	125	4 min	1.5 min	5 min	2 min	20 min	9 min	40 min	18 min	80 min	36 min	2.5 hr	1.1 hr
66	150	3 min	1 min	4 min	1.5 min	15 min	6 min	25 min	10 min	46 min	21 min	80 min	36 min

OM When two Pencils are used in the same charge, the OM is the most likely timing. When only a single Pencil is used, the value should be increased by about 15%.
ST The ST is a reasonably safe time. Timings shorter than the ST should not occur more often than once in a thousand trials.

and for ampule variations averaged 16.2. By percentage of variance was meant the quantity $\sigma' \frac{100}{x}$ where

$$\sigma' = \left[\frac{(\Sigma X)^2}{(n-1)} - \frac{(\Sigma X)^2}{n(n-1)}\right]^{\frac{1}{2}}$$

and where X is the observed timing, x is the deviation from the mean, and n is the number of Pencils firing.

9.12 PERFORMANCE [46, 48, 51]

The data given in Table 4 were obtained from many hundred tests according to the rigorous procedures indicated in Section 9.11; since all operations were conducted using two Pencils, the columns headed OM are most significant. In all cases it should be remembered that the personal idiosyncracy of the user in placing and operating the Pencil in the field may be expected to alter the timings by a factor of as much as 25 per cent. Whether this is serious or not will depend upon an individual operation. In general the condition would be serious only in the short timings, where because of some freak of accumulated effects a functioning in considerably less than the specified period might endanger the user. The figures given in columns headed ST are not of great value, except as indicating the extent of risk which an operator would encounter in using Pencils. This risk is probably not significant under wartime conditions.

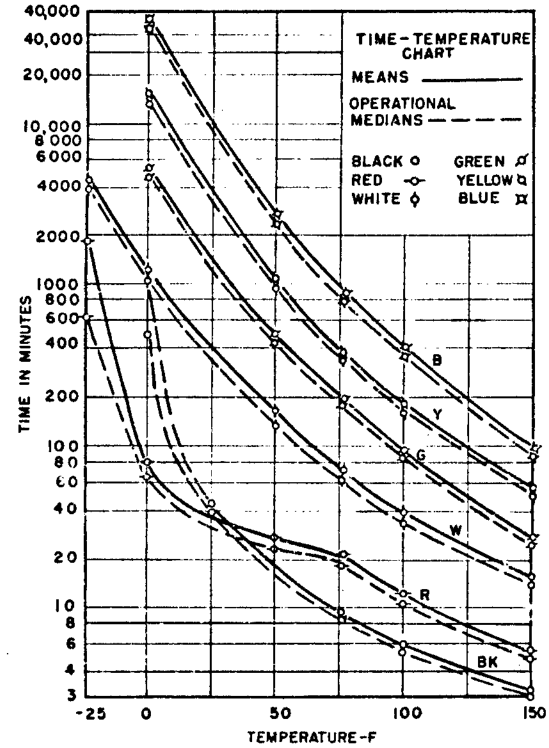

FIGURE 7. Time temperature chart of SRA-3.

The same data, presented in a more forceful form, is found in Figure 7 which shows the relationship between time and temperature for all colors.

Chapter 10

MARK II PENCIL

10.1 INTRODUCTION [9, 10]

The performance of the Mark I Pencil (see Table 4 in Chapter 9) made it abundantly clear that the greatest refinements in production technique would never provide a delay, which in the field would give essentially constant timing for expected temperature changes. Progress could be made in producing delays having less variability and greater reproducibility, but, because the Mark I was based chiefly on a chemical reaction, it would always be subject to wide variations in timings caused by moderate variations in temperature. This is well illustrated by the figures for White delays, which at 0 F required 17½ hr for operation and at 125 F took only 20 min. There was therefore an operational requirement for a time delay having the dimensions and essential operation of the Mark I Pencil but being independent of temperature. This was a realistic approach, for the man in the field could hardly be expected to tell within 5 or 10 degrees what the ambient temperature was and to apply the table of temperature corrections listed for the Mark I.

It appeared that the problem might be readily solved by substituting, for the chemical action of the Mark I, an electrochemical reaction in which the iron tension wire of the Pencil would be one of electrodes of a galvanic cell. The other electrode in this design would consist of a silver wire coated with fused silver chloride. The following reaction would thereupon be set up when electrolyte was added to the system: $\frac{1}{2}Fe + AgCl = \frac{1}{2}FeCl_2 + Ag$. This spontaneous reaction would take place with resulting disappearance of the iron wire at a rate which would depend upon the value of a resistor connecting the iron and silver poles of the cell. The maximum time would be obtained on an open circuit with no connecting resistor and the least time when a short was provided between the two electrodes. Experience soon indicated that a maximum timing range varying between 17 hr and 10 min could thereby be obtained. Since this range was also the range of the Mark I Pencil, the system appeared suitable for use in the development of an improved device.

Being electrochemical in nature rather than chemical, such a device would be independent of temperature, and variation in timing would be obtained, not by changes in electrolyte or electrodes, but solely by variation of the external resistance. The simplicity with which this design lent itself to the basic Mark I features is apparent in Figure 1.

10.2 DESCRIPTION AND OPERATION [1, 10]

Reference to Figure 1 will show that many parts of the Mark I design were retained and that others were only slightly altered to accomplish the change of the Mark I from a chemical to an electrochemical device. The overall dimensions remained constant, with the exception of the end cap, which in the Mark II was slightly larger in diameter than the rest of the Pencil. Its operation was identical with that of the Mark I, in that the user crushed a soft copper tube within which was contained a glass ampule filled with the electrolytic solution. Unlike the Mark I, crushing was preferably performed with the snout end of the Pencil upward so that the released electrolyte might flow to the cell end of the device and there be soaked up by the cotton wick. This will be further discussed in Section 10.4.4. Following crushing, the safety strip would be removed and the Pencil placed in any desired position. Its operation from there on was entirely mechanical and analagous to the Mark I.

The steel tension wire was subjected to galvanic action over that portion covered by the cotton packing in the bakelite end cell. Upon the release of the electrolytic solution, which was either a solution of ammonium chloride or calcium chloride, the abovementioned chemical reaction began, with the result that the iron wire was eroded and the silver chloride electrode reduced. This electrode and the iron wire both passed through the base of the bakelite cell head, were firmly crimped to prevent slippage, and were connected by soldering through a length of standard nichrome, or similar resistance wire, which for convenience was wound on a bobbin cut into the side of the bakelite cell.

10.3 CHANGES FROM THE MARK I DESIGN

10.3.1 Wire [2, 4]

Taking advantage of the discoveries in Mark I research, electrogalvanized steel wire was employed in preference to tinned music wire and a change was

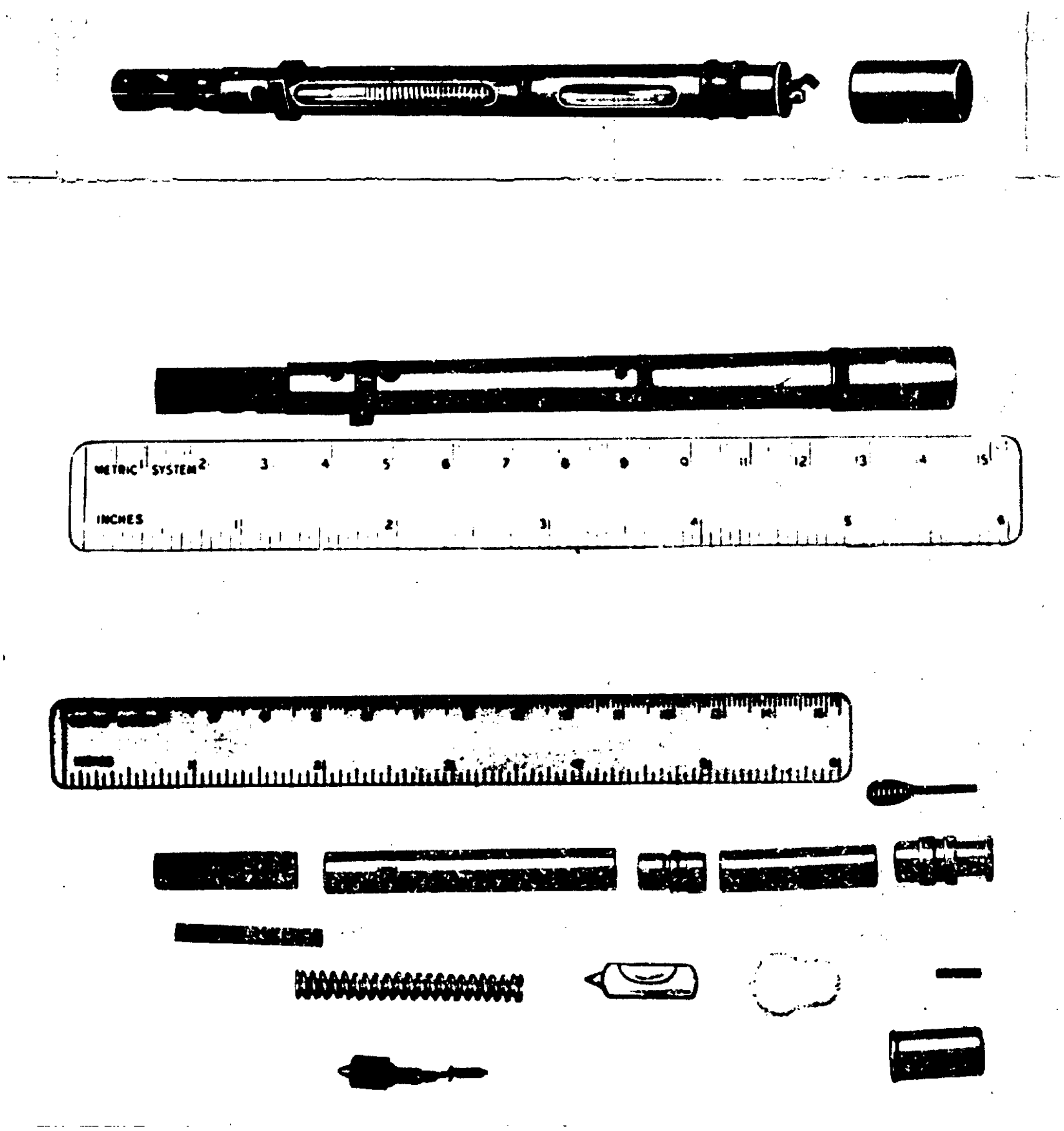

FIGURE 1. Cut-away model, assembled model, exploded model — Mark II Pencil.

made from 20-mil to 10-mil wire to meet the normal timing range of the Mark I colors. Protection of this wire, which was low (0.60 per cent) in carbon, was accomplished by electrogalvanizing to a coating thickness of 1×10^{4} in. $\pm$ 25 per cent. The wire was anchored, both at the cell end and at the striker end, by a new method of attachment. This was necessitated because the set screw used in the SRA-3 could not be employed in the Mark II on account of the limited space at the end plug. Anchoring was obtained when a small strip of fine, hard-temper copper tube was slipped over the galvanized wire and crimped in a double V by a special tool. Numerous tests showed that this method of attachment was firm and that the wire would invariably break before the V-crimp would loosen. It was, of course, essential that, on crushing the copper tube, the iron wire should not make contact with the copper to provide

a short. This could be corrected either by lining the copper tube of the reaction chamber with an insulating material or by covering the iron tension wire with a sheath of similar material. The former procedure was found definitely preferable.

10.3.2 Solution [2, 3, 4]

It was shown that, as the volume of the solution was increased beyond a certain value, the mean time tended to increase and the precision of timing to decrease. As the volume was decreased, the reverse took place and duds appeared. Fortunately between the range 0.20 and 0.25 cc the curve of the mean time versus the volume of solution became almost flat and the precision of time attained a maximum. Hence the volume of the solution was fixed at 0.23 ± 0.01 cc.

It was originally intended to use ammonium chloride as the electrolyte for all the Pencil colors. However, it was soon found that in the longer delays (White through Blue), the time of operation of the delay was sufficient for a slow, secondary reaction to take place involving iron and ammonium chloride. Calcium chloride solution did not give this slow spontaneous corrosion of the steel wire, and hence was desirable for the longer timings. In the lower timing ranges, however, calcium chloride solutions were appreciably inferior to ammonium chloride with respect to temperature coefficient. Hence two solutions were eventually used for the whole range of the Mark II Pencil: a solution containing 17 per cent ammonium chloride for Black and Red Pencils, and a solution containing 20 per cent calcium chloride for the other colors. To these solutions was added 5 per cent by volume of *n*-propanol, which functioned as a wetting agent and increased the speed with which the wick could soak up the released electrolyte.

The use of the same solution for all Pencils would have simplified manufacturing and would have eliminated any possibility of incorrect ampule assembly. If this were sufficiently important, calcium chloride would be preferred, but in that case the Black Pencil would have a mean time of 12 min instead of the specified 10. It should be evident that the change from copper chloride glycerin solutions to those consisting only of ammonium or calcium chloride and propyl alcohol simplified production. Moreover, the concentration of the solutions was easy to control and the functioning of the Mark II Pencil was not sensitive to even gross variations.

10.3.3 Ampules [6]

Since the Mark I Pencil in its final form required an ampule containing 0.7 cc of solution, the change in the Mark II necessitated the production in quantity of a very much smaller ampule. This caused some difficulty, especially in the sealing operation where the presence of the propyl alcohol was objectionable and where calcium chloride tended to wet the glass and to spoil the seal. However, with the assistance of several manufacturers, the problems connected with the new ampule were overcome and test procedures were set up which eliminated weak ampules. An entirely satisfactory ampule production was achieved, and properly made ampules were found to withstand heating to 180 F and to be resistent to moderately rough handling.

10.3.4 End Plug

The brass end plug of the Mark I design was replaced by a bakelite cell unit bearing, as already mentioned, the silver-silver chloride electrode and provided with a small hole through which passed the iron tension wire to be crimped and soldered at the back of the plug. Manufacture of the bakelite cell was not a difficult screw machine problem. The chief difficulty with the part occurred in producing the silver-silver chloride electrode and in inserting the cotton wick. A spoon-shaped electrode, formed from wire and coated with molten silver chloride by machine dipping, gave good performance. The theoretical amount of silver chloride needed was about 20 mg and the production electrodes were provided on the average with twice that quantity.

10.3.5 Wicks [3, 6]

Absorbent cotton pellets were used to stuff the bakelite cell and to bring the electrolyte into intimate contact with the electrodes. It was found that the weight of these pellets influenced the mean time and the precision of timing with the optimum weight lying between 35 and 40 mg. Preformed dental rolls of the right weight and dimensions were obtained for the semi-production and would presumably represent no problem to a future producer of the device. They would be essential, since only by their use could assurance be given that each Pencil had received exactly the correct weight of wicking.

10.3.6 Copper Tube [2,3,4,6]

Because the length of the SRA-3 was maintained while the end plug length had been considerably increased, the crushable copper tube comprising the reaction chamber had suffered in overall length. The effect of this was to make it stiffer to crushing when located in an assembled Pencil. To match the easy crushing properties of the SRA-3, another tube had to be employed. Fully annealed tubing was used, and the wall thickness (0.11 in.) was adjusted to give this appropriate stiffness. It was coated to provide insulation of the reaction cell, by dipping in Roxalin Flexible Lacquer No. 3181.

10.3.7 Center Plug [6]

In the semi-production of the Mark II which was undertaken by the division, the center plug of the Pencil was identical with that used in the Mark I, except that the Plasticine sealing compound was omitted. Subsequent tests indicated that this was a mistake, and in any future production sealing of the reaction chamber from atmospheric corrosion by the use of Plasticine should be retained.

10.3.8 Spring [5]

With a change in the diameter of the tension wire and a drop in its breaking load from the Mark I value of 35 lb to the Mark II value of 29 lb, a corresponding reduction was required in the weight loading of the spring. It was impossible to use the same spring employed in the SRA-3, since full loading to 15 lb was required to reduce the length sufficiently so that the striker would clear the inspection port. A new spring was therefore specified for the Mark II, and it was determined that it could be safely loaded to 10¾ lb without fatigue and still deliver a force sufficient to fire the primer caps of the standard SRA-3 reliably.

10.4 PERFORMANCE [7, 8]

10.4.1 Temperature Coefficient

The great virtue of the Mark II Pencil was the independence of its timing to temperature change, as shown by exhaustive tests conducted at the central laboratory of the division and by the developing contractor. Figure 2 gives the values obtained by these extensive tests and shows, more clearly than words, the remarkable performance which the Mark II possessed. The same figure bears the corresponding curves for the SRA-3 and the improvement is noteworthy. The letters refer to the colors.

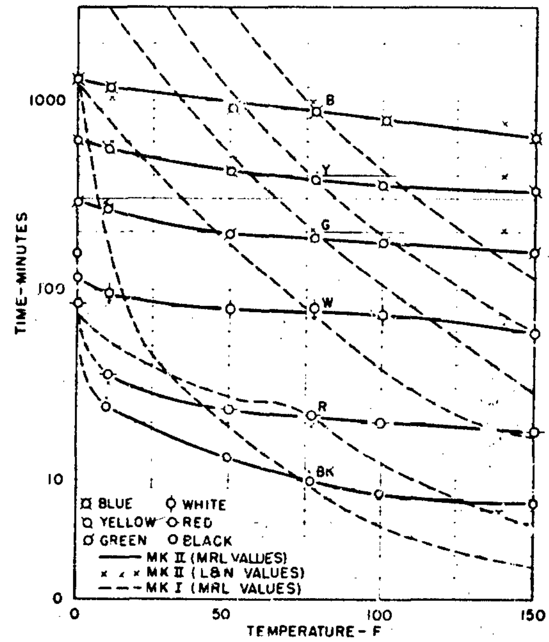

FIGURE 2. Time-temperature chart—Mark I and Mark II Pencils.

10.4.2 Per Cent Deviation

It was interesting to learn that, although not anticipated, the percentage deviation of the Mark II Pencil was in general equal to or lower than that obtained with the Mark I (see Section 9.11.2). In Figure 3 are plotted the values of this function for the different colors.

10.4.3 Tropical Weathering [8]

The resistance of the Mark II Pencil to prolonged storage was determined and compared with the performance already obtained with the Mark I, which, it will be recalled, required individual packaging in polyvinyl chloride tubes to insure arrival of the device in a usable condition in the field. After tests at the division's central laboratory, it appeared that the Mark II Pencil was somewhat more sensitive to prolonged exposure to high humidity and high temperature than the Mark I. This feature was, however, not of a different order of magnitude and presumably the Mark II Pencil if properly protected in the recommended manner would give no difficulty in the field.

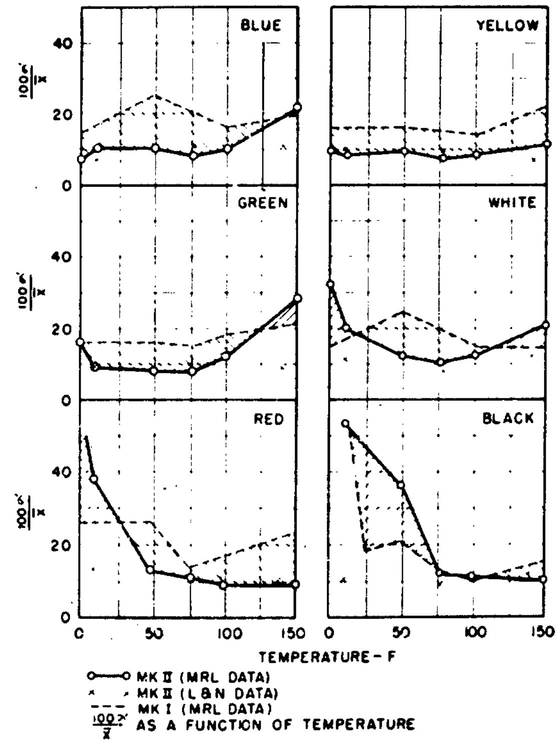

FIGURE 3. Reproducibility of Mark I and Mark II Pencils.

10.1.1 Positional Operation [8, 9]

Throughout the development of the Mark II Pencil, the interested liaison officers in OSS and the Corps of Engineers were acquainted with the fact that, for optimum performance, the Mark II Pencil required initiation with the cell end down, so that the crushed ampule could deliver its contents to the wick. By numerous tests it was shown that even this requirement was not critical and that crushing could be conducted in almost any position except with the snout end down and, if followed by a whipping or tapping action, would give reliable performance. From a technical point of view it did not appear that this added requirement in the use of the device would be a serious limitation.

Such turned out to be the case, however, when field appraisal was obtained using the NDRC semi-production models.[9] It appeared that those in charge of training users of such delays did not care to grapple with the additional requirement of positional activation, even though admitting that the Mark II Pencil, by its superior temperature performance, had given a delay of much greater value for special field use than the original Mark I Pencil. Whether a redesign of the Mark II Pencil could be undertaken which would provide for this deficiency is a matter of question. Unfortunately the development reached completion too late in the war for the division to have undertaken the study.

It was believed, and is still the opinion of the writer, that the advantages of the Mark II more than outweighed this mild inconvenience in its use. It is believed that this can be shown in no more convincing way than by Table 1 in which the temperature coefficients of the SRA-3 and the Mark II Pencil are compared.

TABLE 1. Comparison of temperature coefficients of SRA-3 and Mark II Pencil.

Color	Ratio of mean timing at 10 F to 150 F SRA-3's	Mark II Pencils
Black	46	3.4
Red	11	1.9
White	47	1.7
Green	104	1.7
Yellow	133	1.6
Blue	248	1.8

Chapter 11

INCENDIARY PENCIL (SRI)

11.1 INTRODUCTION

Both the Mark I and the Mark II Pencils, discussed in Chapters 9 and 10, were designed for the activation of explosive devices or charges. They could equally well serve the purpose of initiating incendiary charges, and this chapter describes how that was achieved.

Two methods were employed, in both cases depending upon the development of a Matchhead which would be activated by the mechanical operation of the time Pencil. In the first case, the primer and spring snout ending of the SRA-3 were replaced by the Matchhead ending, which was crimped into the brass striker tube of the Pencil. In the second case, the SRA-3 was used as it stood and the Matchhead was simply inserted into the spring snout in juxtaposition to the primer cap. The former type of use was silent, but the latter made the usual noise of the exploding primer. In certain operations this feature would not be serious, in others silence might be a requirement; hence, the probable need for both types of usage of the Matchhead in field operations. Needless to say, the second type recommended itself particularly, in that no alteration in the standard SRA-3 was required for conversion to the Incendiary Time Pencil.

11.2 DETAILS OF CONSTRUCTION

11.2.1 Magnesium Matchhead [1]

In its final form the most satisfactory Matchhead developed consisted of a magnesium cell made by reaming out a rod of magnesium. It had an overall length of $1\frac{5}{16}$ in., an outside diameter of 0.278 in., and an inside diameter of 0.218 in. Nearly two-thirds of this cavity was filled with a hot burning composition known as BA-29-A as follows: barium peroxide anhydrous, 75 ± 3 per cent; potassium perchlorate, 3 ± ½ per cent; red iron oxide, 9¼ ± 1 per cent; magnesium powder Grade A coated with 3 per cent linseed oil dried 24 hours, 12½ per cent; paraffin oil, ¼ per cent. This material was pressed by hand into the magnesium case and was followed by a small volume of SM composition having the following specifications: potassium chlorate 47 ± 2 per cent; magnesium powder Grade B coated with 3 per cent linseed oil dried for 24 hours, 10 ± 1 per cent; hard wood flour, 6 ± 1 per cent; infusorial earth, 5 ± 1 per cent; red iron oxide, 10 ± 1 per cent; powdered glass, 12½ ± 1 per cent; ½ second nitrocellulose in 60 per cent ethyl acetate and 40 per cent butyl acetate, 9½ ± 1 per cent. The last ingredient of this composition made it sufficiently moist to be plastic, and, while in this state, there was inserted into it the head of a Strike-Anywhere match. This was squeezed down to a distance of 0.020 ± 0.010 in. from the end of the magnesium body. The unit as assembled was then dried at room temperature for 40 hr, inspected for uniformity, and sealed against moisture by a drop of molten Lukon wax compound heated to 300 F. After inspection, the Magnesium Matchheads were pickled in a standard acid solution to give them resistance to corrosion.

When assembled, by crimping into the standard Pencil, a modified Pencil known as the *signal relay incendiary* (SRI) resulted. This required a slight modification in the striker of the SRA-3. In contrast to the shape required for firing a primer cap, the Incendiary Matchhead required a sharp-pointed needle. Figure 1 illustrates this, as well as the assembled device. The point of this striker formed an angle of 45 degrees and was roughened by a Parkerizing technique. The body of the striker, as seen in the illustration, was provided with several vent holes to prevent explosions from the large volume of gas liberated by the quick-burning compositions.

Operation of the Pencil in the usual manner gave essentially silent initiation of the Matchhead when the striker point penetrated the wax coating and pierced the underlying safety Matchhead surrounded by the quick-burning compositions. These in turn ignited the magnesium casing, which burst into flame. If the Matchhead were to be used by the second technique outlined in Section 11.1, the user would first be required to remove the protecting wax overcoat so that the flame from the primer cap could each the embedded safety Matchhead and initiate it. This usage is illustrated in Figure 2.

11.2.2 Celluloid Matchhead [4, 8]

A preliminary design, differing from the one described immediately above, chiefly in the fact that

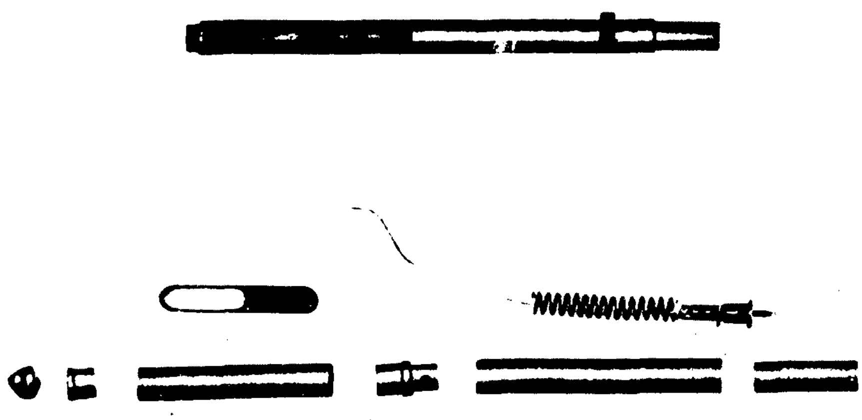

FIGURE 1. SRI-Mg: assembled and exploded views.

the case was celluloid rather than magnesium, was also developed. However, considerable difficulty was encountered in making the Celluloid Matchhead impervious to water vapor because celluloid passes moisture. Attempts to give this Matchhead protection under adverse storage conditions occupied testing laboratories for many months, and eventually some success was attained by the use of a thin, transparent celluloid window in place of the sealing wax mentioned in the Magnesium Matchhead. Further improvement resulted on dipping in thermoplastic wax Dewey and Almy No. TP317.

Crimping of this type of head into the SRA-3 sometimes caused minute fissures to appear in the protecting surface and, under very prolonged storage at high humidity and high temperature, failure of the device frequently occurred because of the penetration of water vapor to the water-sensitive filling. This prompted the change to the magnesium case, which was recommended by the division as the final solution to the problem. Unfortunately, production of the Celluloid Matchhead was many times larger than the Magnesium Matchhead because of its earlier development.

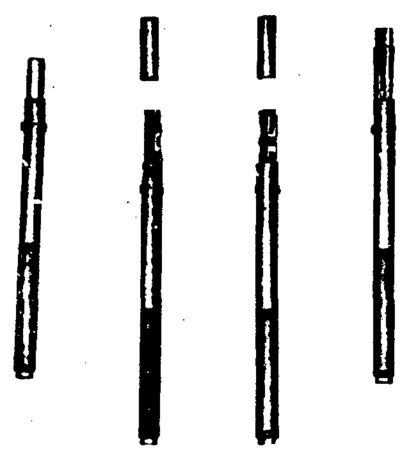

FIGURE 2. The method of using a separate magnesium igniter in a standard SRA. From left to right: The SRI-Mg; SRA and magnesium igniter; SRA and magnesium igniter with wax covering of Matchhead removed; magnesium igniter inserted in spring snout of SRA.

11.3 PERFORMANCE [7]

11.3.1 Resistance to Weathering [2]

Exposure of SRI's to extremely severe cycling conditions indicated that in the case of the magnesium head, reliable performance could be guaranteed for several times any period obtainable with a standard time delay Pencil. The Matchheads would not, however, withstand indefinite treatment of this severity any more than would the unpackaged SRA-3's. The recommendation was made therefore that the SRI's

be packaged in watertight containers, similar to those which had already been shown necessary for the SRA's (see Section 9.10). This guaranteed the arrival of the SRI in the field in a perfect condition and assured its satisfactory performance.

11.3.2 Use as an Incendiary [5]

The SRI in itself proved to be a simple, reliable, and extremely small incendiary device for the ignition of targets having a fair combustibility. Numerous tests on a number of wooden structures showed that placement of an SRI between two vertical wooden surfaces 1 in. apart would give reliable ignition, provided the water content of the wood did not exceed 15 per cent. This figure was reasonable for most wood stored indoors or in hot, dry countries. For ignition of more difficult targets an auxiliary incendiary material would have to be provided.

It was found also that the efficiency of an SRI could be considerably increased by the use of it in conjunction with several additional Magnesium Matchheads; Figure 3 illustrates this application.

With multiple heads arranged in this manner, there was a delay of 6 to 10 sec between the ignition of the successive heads, which were arranged so that the waxed end was flush with the solid magnesium end of the next head. This arrangement was required, for, if the igniter heads were joined so that the magnesium was heated before the Matchhead was lit, there was a considerable probability of detonating the igniter mix. By such a simple procedure as illustrated in Figure 3, the effectiveness of a single SRI could be more than tripled.

11.3.3 Use as an Igniting Fuze [3, 6]

The first value of the SRI was in combination with incendiary devices having a large charge of fuel, and its use there was very general. It could be counted upon to ignite thermite through the use of a first fire mixture, jellied petroleum munitions, and has already been specifically mentioned in Chapter 2, where it was used with the Paul Revere to ignite a magnesium "goop."

Indeed, wherever a delayed action incendiary of great potency was needed, the SRI could be recommended. This could be done either directly by pick-up of the fire from the burning Matchhead or indirectly by the use of safety fuze, for it was found [6] that the SRI was well adapted to silent, time delay ignition of safety fuzes. If one end of the fuze were split with a sharp knife for a distance of about 1 in. and the cut faces taped onto the magnesium head of the SRI, the safety fuze was reliably ignited. In this way silent ignition with further delay could be used in those cases where safety fuze was required for operational reasons.[3]

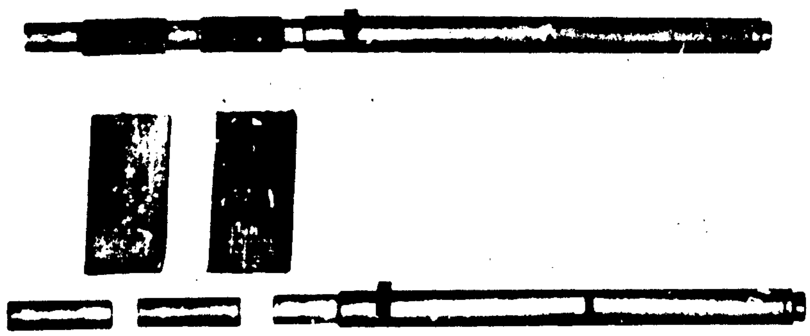

FIGURE 3. SRI-Mg with triple head: assembled device and separated parts.

Chapter 12

CLOCKWORK TIME DELAY (DEMOLITION FIRING DEVICE MARK 3)

12.1 INTRODUCTION

There are occasions in demolition operations when it is desirable to have a time delay fuze of greater accuracy and of longer delay timing than can be provided by such chemical and electrochemical systems as have been described in Chapters 9 and 10. These operations may be either under water or above. A general requirement would therefore seem to exist for a small waterproof, cheap, and accurate delay. Such requirements can in practice be met most practicably by a fuze based upon an inexpensive clockwork. No originality is claimed for this idea, however, it would seem that the American Services lacked a device of the general characteristics described. This was in spite of the fact that practically every other Army in the world was well equipped along these lines. The Germans in World War II made frequent use of clockwork delay fuzes, of which they had an abundance of types and models, for they were fortunate in having at their disposal the skilled watch makers of southern Bavaria and Switzerland. The result was a large number of delays varying from a few minutes to as many as 21 days in operation and from the crudest to the finest workmanship.

The British were keenly aware of the lack of such delays for use by individuals and demolition squads and had laid down a tentative specification for a suitable fuze.[3] Their work proceeded simultaneously in Britain with development done by Division 19 and resulted eventually in a model based upon the Eureka clock, a mechanism used as standard equipment in British planes.[5] Neither this nor any of the German models which were made known to workers in Division 19 appeared satisfactory in meeting the rigorous requirements laid down by OSS and later confirmed by the Bureau of Ordnance of the Navy Department. These specifications included the following constructional and operational features, all of which were eventually met in the designs discussed below.[1]

1. The timing element, except in the multi-day models, was inexpensive, robust, and readily available.
2. The accuracy of operation was essentially that of the watch mechanism, and accurate setting was possible by retaining the function of both the hour and minute hands.
3. The device was as compact as possible, measuring approximately 2½ in. square and 1¼ in. deep.
4. It was unaffected by temperature changes between −4 and +113 F, by severe vibration, by immersion in water to depths of as much as 70 ft, or by magnetic fields.
5. The safety and starting means were so designed that they might be operated under water without danger of leakage.
6. The safety pin was designed so that it could not be removed, if the device had fired or was about to fire. Its position was readily discernible at all times, and misoperation was prevented by an interlocking linkage.
7. By means of a plastic window, the setting was visible, and a user could select any time desired. These times varied for the 12-hour delay between 15 min and 11¾ hr, for the 24-hour delay between 30 min and 23½ hr, and for the multi-day delay between 15 min and 6 days.
8. The operation of an individual device could be tested by the user prior to actual use and the device reset without difficulty.

The device, meeting the above rigorous specifications and combining considerable robustness and resistance to adverse conditions, was eventually produced in the 12-hour and 24-hour models in considerable number by the Bureau of Ordnance and OSS. These were of interest and use also to the Engineer Board at Fort Belvoir, Virginia. Production was not without the usual difficulties and Section 12.6 of this report will indicate a few of the pitfalls which could be avoided in a future procurement. Nevertheless, the various models were considered as easily manufacturable under good quality control and extremely reliable in operation. It was not believed that any foreign devices known to the division could equal the Mark 3 in its fulfillment of so many points.

12.2 12-HOUR MODEL[1, 2]

12.2.1 General Description

Figures 1, 2, and 3 show the 12-hour firing device Mark 3 in three different views. In Figure 1 a phantom view is shown, from which it is clear how the

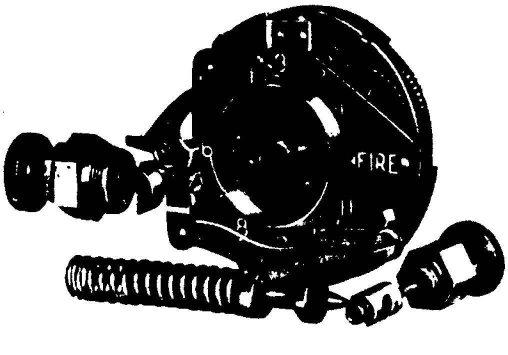

FIGURE 1. Phantom view of parts of 12-hour model.

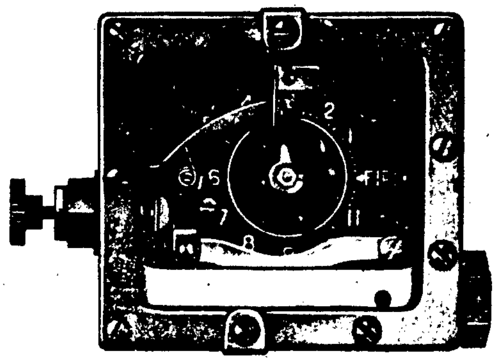

FIGURE 2. Assembled view of 12-hour model.

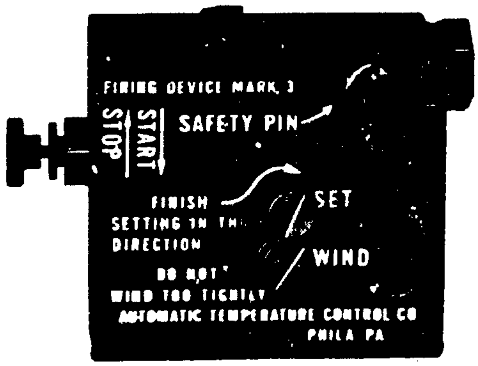

FIGURE 3. Back view of all models.

mechanism functions and how safety and starting are provided. In Figure 2 and 3 are shown the front and rear views of the production models.

Two knurled thumb screws projected from the case. The one in the back operated the safety, while the other located at one end started the device. The two plugs in the back of the case provided access for winding the watch movement and setting the delay. The main body of the case was of cast aluminum, while the back plate bearing the engraved instructions was of iron, providing a certain amount of magnetic protection. The front was covered by a transparent plastic window, held in place by a rubber gasket. For shipping, the firing end was closed by a plug, shown in the side of the case in Figures 2 and 3. For use this was removed and a suitable detonating train inserted for operation by the action of the spring-loaded striker. The case was made watertight by the use of gaskets, luting, and stuffing boxes.

A watch movement of the cheap pocket watch type was selected because of its availability in quantity and robustness. The particular movement used was a back-wound and back-set type made by the New Haven Clock Company. This was selected in preference to a stem-wound and stem-set type, because the latter might stop, if the user failed to return the stem to the normal position after setting. The watch movement was slightly modified. The usual hour hand was replaced by a cupped disk having a narrow slot in its circumference (see Figure 1), and internal friction of the device was modified to increase reliability, while minor changes were made in other elements. The minute hand was retained to secure precision of setting, thus correcting a major fault of the usual mechanical type delay mechanism.

A study of Figure 1 will show details of the mechanical operation. A sear held the striker with compression of the striker spring. One end of this sear was held by a fixed pivot, while to the other end was pivoted a latch. When the mechanism was cocked, the free end of this latch abutted against a roller carried by a fixed pivot and a tripping lever. The latch was tripped to release the firing device when the projection on the lever end fell toward the center of the mechanism through the slot in the hour disk. The movement, under the action of a coil spring, released the latch and sear, and the device fired. It will be seen from Figure 1 that premature firing would be impossible because of the position of the safety directly in front of the firing pin. Premature operation would securely lock the safety and prevent its withdrawal.

Figure 1 also shows the starting knob. When this was turned in a clockwise direction, it allowed a slight movement of the tripping lever, so that the projection on its end rested upon the smooth outer wall of the hour disk. In the same operation, a slight movement was imparted to the balance wheel of the clock, thus insuring the starting of the mechanism. Prior to operation, the inserted starting knob held the tripping lever free from the hour disk, allowing ready setting of it and preventing a misfire during that operation.

12.2.2 Method of Use

An operator would first assure himself that the watch was wound, the mechanism cocked, and the safety in the safe position. He would then remove the back plug and set the time delay by means of a small key provided with each device, while noting that the disk was the hour hand and the pointer the minute hand and that the figures on the dial progressed in the opposite direction from those of a standard watch. After replacing the plug securely against the waterproofing gasket and attaching a suitable firing end, he would turn the starting knob clockwise and then pull the safety out, locking it in the non-operative position by a twist counterclockwise. Should it be desired to prevent stopping of the movement or replacement of the safety, both knobs were provided with soft alloy stems and could be broken off after an original placement. On the other hand, if the user wished to assure himself that the device was in satisfactory condition he could fire it prior to use and reset it by inserting a suitable rod into the barrel and compressing the striker spring until the sear fell downward into position again. While maintaining this pressure and position, a turn of the starting knob counterclockwise would pick up and move the tripping lever through the slot in the hour disk back to its original position, where it would be retained by the starting knob while the hour disk was reset. The safety could then be re-inserted and the device would be in the same condition as originally delivered.

The special features of this design which are believed to be noteworthy are: the functioning of the starting knob to provide protection against premature firing during setting, to allow resetting, and to insure operation of the clock movement; the function of the safety which allowed underwater setting of the device with complete protection to the user; and the setting accuracy which was provided by the retention of the minute hand.

12.3 24-HOUR MODEL [1]

This differed from the 12-hour model only in that the clockwork mechanism was so modified that the hour disk made a revolution in 24 hours instead of in 12 hours. The only other change required was the partition of the scale into 24 major devisions instead of 12. The minute hand was retained as before, and the dial was provided with the usual minute divisions.

The simplicity with which this could be made suggested that other time periods would be possible using the same inexpensive New Haven movements. Models were constructed of a one-hour delay and of even shorter delays but were never produced. The one-hour delay was made by modifying the watch so that the hour disk made one complete revolution in one hour. The maximum delay period was 59 min, and the minimum setting was about 1½ min. Otherwise, except for a difference in the scale, all parts were identical with those used in the 12-hour delay. For delays of less than one hour, the rate of movement of the hour disk was altered by removal of the teeth from the escape wheel. Since the movement had a 17-tooth escape wheel, removal of 16 of these teeth increased the rate of the watch movement approximately 15 times. The effective rate of such a modified watch was the average of two different rates: the usual one when the teeth were driving the balance wheel, which acted as a regulator, and a much higher rate when the escape wheel slipped where the teeth were missing. However, the frequency of alteration between these two rates was sufficiently high, so that the average rate of the watch was fairly constant. The maximum delay period obtained with this delay was 3½ min, the minimum setting about 0.1 min. Models of this type would probably have only limited usefulness in very special cases, mostly in the very short delays which are now so adequately met by the use of standard safety fuzes having remarkable reproducibility of burning per unit length. The increased precision gained by having a clockwork mechanism capable of functioning only over a span of one hour would probably not be sufficient to recommend its preference over the standard 12-hour delay, whose accuracy was good.

12.4 MULTI-DAY MODEL [1]

It was believed desirable to reach the upper limit in practicable timing, using the Mark 3 design. In going beyond a total delay period of 24 hours, a change in

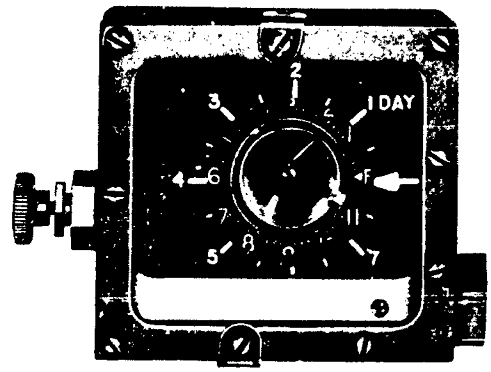

FIGURE 4. Multi-day model.

clockwork movement was required, for the inexpensive pocket watch type used in Sections 12.2 and 12.3 did not have a spring sufficient to provide assured operation for a period beyond 24 hours.

On the other hand, it was desired that the standard cast aluminum case of the Mark 3 model be retained, together with identical triggering and firing system. This meant the location of a robust and very compact 8-day clockwork. Two makes of watches were available for the purpose, both of them standard with the Navy for aircraft clocks: Elgin Model 5620 and a Longine-Wittnauer. The former was definitely preferable because of its less fragile construction. Modifications required of this movement for the intended purpose were slight. The winding and setting shafts were altered to bring them out the back, thus providing the back winding and back setting feature already mentioned in Section 12.2. The hour hand was replaced by two disks concentrically mounted. The outer disk rotated once in the maximum delay period, which in practice was found to be not over 6 days. The inner disk rotated once in 12 hours. The minute hand was retained and referenced with the usual hour and minute dial, so that setting was as accurate as with the 12-hour delay. The dial provided to reference with the day disk was subdivided into half-day divisions and was separate from the usual dial and placed above it. It was provided with a circular opening through which the tripping lever and the hour and minute dial could be viewed. It is believed that Figure 4 shows this arrangement clearly.

In operation the tripping lever was held by the outer disk during a period of days, until the slot in that disk permitted the lever to fall through, whereupon its projection rested upon the hour disk until the proper hour and minute arrived when the slot in that inner disk allowed the lever to continue its travel, releasing the sear and the striker. This model required in addition a slight reworking of the aluminum casting standard with the 12-hour delay.

If production were to be undertaken, a more robust movement would have to be provided. This could be done by reducing the weight of the plates in the movement and increasing the diameter of the shafts. The device would then withstand much rougher handling with no increase in weight or bulk. If an 8-day delay were desired, a stronger main spring would have to be provided. Only experimental models of this type were constructed in view of its late development in the war.

12.5 PERFORMANCE

12.5.1 Against Vibration and Magnetism [1]

Table 1 illustrates the independence which the various models showed to vibration on a test board run at 1900 cycles per min and an amplitude of 0.020 in.

TABLE 1. Results of vibration test on clockwork delays.

Model	Delay setting	Actual time elapsed	Difference in minutes
12-hr production unit	60 min	59.7 min	− 0.3
24-hr, No. 2	2 hr	1 hr 56.5 min	− 3.5
24-hr, No. 5	2 hr	1 hr 59.75 min	− 0.25
1-hr	59 min	58.84 min	− 0.16
Multi-day	3 hr	2 hr 58.8 min	− 1.2

Table 2 shows the inconsequential effect of a magnetic field provided by six ½-lb Alcomax magnets, each requiring a pull force of about 50 lb for removal.

TABLE 2. Results of test for magnetic field protection.

Model	Delay setting	Actual time elapsed	Difference in minutes
12-hr model			
Standard run	11 hr 45 min	11 hr 49 min	+ 4.0
Test run	11 hr 45 min	11 hr 48.75 min	+ 3.75
Multi-day model			
Standard run	24 hr	23 hr 59.0 min	− 1.0
Test run	24 hr	23 hr 59.25 min	− 0.75

12.5.2 Against Weathering and Humidity [1, 8, 9]

Tests included simulated tropical conditions involving exposure to an average temperature of 145 F and 95 per cent relative humidity for 28-hour periods and an intervening rest period of 16 hours. The usual change in timing which resulted thereby was well within the errors observed in Tables 1 and 2. Tests at high temperature with ordinary humidity (113 F) likewise produced no serious variation in performance (see Table 3).

TABLE 3. Results of high temperature test with ordinary humidity.

Model	Delay setting	Actual time elapsed	Difference in minutes
12-hr	7 hr 30 min	7 hr 31.4 min	+ 1.4
1-hr	59 min	58.96 min	− 0.04
Multi-day	7 days	7 days 0 hr 7.75 min	+ 7.75

More serious than either of these conditions was the low temperature test. Here it was expected that trouble would appear because of freezing of the lubricant. Fortunately, this difficulty was entirely eliminated by the use of a special synthetic lubricant manufactured by the Elgin Watch Company and known as No. 56A.[1] Before starting the watch, the unit was exposed to a temperature of −20 F for approximately 12 hours, given a 2-hour recovery at −5 F, and then started and allowed to run at that temperature. Table 4 gives typical results.

TABLE 4. Results of low temperature test.

Model	Delay setting	Actual time elapsed	Difference in minutes
12-hr	11 hr 20 min	11 hr 22.5 min	+ 2.5
24-hr	1 hr	0 hr 59.0 min	− 1.0
1-hr	59 min	58.97 min	− 0.03
Multi-day	6 days	5 days 23 hr 55 min	− 5.0

12.5.3 Against Rough Usage

In these tests a unit was set for a delay of 30 min, but was not started and was then dropped three times from a height of 5 ft onto concrete. Some mechanical damage to external features resulted, but no apparent damage to the mechanism itself. The watch was then started and run normally for 10 min, when the second half of the test was performed. The delay was set for one hour and started; it was then dropped three times from a height of 5 ft onto concrete as before. Good performance following this drastic treatment was not always obtained, although there was very satisfactory behaviour of the vast majority of the units.

12.6 MANUFACTURE [1, 6]

The specifications [6] laid down for the original manufacturer of the 12-hour model were arrived at jointly by the division's contractor and the Bureau of Ordnance. They appeared satisfactory, provided they were adhered to by rigid quality control. One of the services given by the division was critical advice to the manufacturer by the original developer of the Mark 3 design. As a result of this advice and Navy concern with reported failures [7] in the field, the early production was inspected and, in part, reworked. This served to eliminate a number of points which had needlessly been allowed to crop up because of inadequate inspection at the start of production. These points included such defects as leakage under water pressures of less than 20 ft, sticking trip levers, serious misassembly of the movement in the case, slipping main springs, and so forth. It appeared that none of these defects were caused by the design but rather to the lack of appreciation at the start by the manufacturer of the importance of close adherence to the specifications. Even so, the admittedly improved production would be estimated to give 85 per cent performance as it stood. Any future production would presumably be based upon the amended specifications, and with this word of caution should encounter no difficulty. The testing of a number of production mechanisms by the central laboratory of the division entirely confirmed this judgment.[8, 9]

Both OSS and the Navy Department insured the delivery of the Delay Firing device to the field in perfect condition by packaging them in hermetically sealed tin containers. Whether or not this requirement was essential, it did provide additional protection.

12.7 CONCLUSION

It was demonstrated that clock-operated delays based upon cheap, readily available movements could be produced in numbers to cover a wide range of timings. Models tested covered the range from

0.1 min to 23½ hr, using a cheap movement and a range of 15 min to 6 days using a more expensive movement.

Delays having nominal timings of 12 and 24 hours were manufactured in quantity. They proved highly accurate and insensitive to temperature changes, rough handling, and extremely unfavorable weather conditions. It is believed that a useful fuze was delivered and that a need of both the Army and the Navy was thereby fulfilled.

Chapter 13

BASES FOR TIME DELAY FUZES

13.1 INTRODUCTION

In preceding chapters in this volume a number of time delay fuzes have been described: the clockwork type, which was both accurate and inexpensive and suited for use either below or above water (Chapter 12), and the SRA, the SRI, and the Mark II Pencil, which were relatively inaccurate but easy to produce in quantity and very cheap (Chapters 9, 10, and 11).

The latter type of fuze was entirely unsuited for use below water, and the need therefore existed for a counterpart to the Pencil which could be used for marine demolitions. Such a fuze already existed in the so-called AC delay (Acetone Celluloid), a British development. This fuze was produced in the United States by OSS, following exactly the British specifications. It is described in Section 13.2 only because the division's central laboratory modified the fuze to provide both shorter and longer timings than the original specifications gave. The remainder of the chapter summarizes the negative experience of the division's contractors in a search for a system which could supplant either the Pencil time delay or the AC delay in scope, cheapness, and usefulness and which would have the additional features of better reproducibility and greater independence to temperature change.

Section 13.3 dealing with organic fiber delays is of interest primarily because the systems investigated had a zero temperature coefficient. Section 13.4 describing magnesium alloy delays is interesting because of the compactness and simplicity of design. The other sections deal with physical and chemical systems which did not prove profitable or were unexplored.

13.2 MARK I AC DELAY

13.2.1 The Standard Delay

This device consisted of a heavy brass tubular body threaded at both ends to receive at the bottom a primer and detonator system and at the top a brass screw cap. Close to the bottom was located an auxiliary part consisting of a firing pin held under spring tension by a celluloid washer and poised directly above the primer cap. In the chamber above the washer was located a glass ampule containing an organic solvent mixture. The cap at the top of the fuze was provided with a screw knob which on being turned moved a piston protected by a rubber sheath down against the glass ampule. This eventually resulted in crushing of the ampule and releasing of the organic solvent for action on the celluloid washer. This attack consisted entirely of physical softening and solution and proceeded to a point where the washer was so weakened that it could no longer support the firing pin under the spring tension; thereupon the device fired. Its solid brass construction insured waterproofness, even to depths as great as 70 ft.[6]

There was some effect due to position [5] but it was found that even if the fuze were mounted with the ampule down when crushed so that the liberated organic solution never actually wetted the celluloid disk, firing nevertheless took place, although after a much prolonged interval due to the attack of the organic vapors on the washer. The temperature effect was considerably smaller than that encountered in the Mark I Pencil (SRA-3) and in any case could not be expected to be as serious, inasmuch as the AC Delay was intended primarily for marine use where the temperature range would be limited presumably to between about 30 and 80 F.

As in the case of the Mark I Pencil, different timings were provided by variations in ampule contents. The British and American practice was to give the user with each delay a kit of several ampules containing differently colored solutions. The user could thereupon select the ampule for his purpose and assemble it in the delay. Table 1 is a time-temperature chart of recommended operational timings.

TABLE 1. Recommended operational timings for AC Delays.

Temp	Red hr	Orange hr	Yellow hr	Green hr	Blue hr	Violet days	Temp
41 F	6½	12½	23	34	80	9	5 C
50 F	5½	11	19	29	61	7	10 C
59 F	5	9½	16	24	48	5	15 C
68 F	4½	8	14	20	39	4	20 C
77 F	4	7	12	16	32	3	25 C
86 F	3½	6	10	14	26	2	30 C

The effect of position on the above timings was de-

termined using green ampules. On horizontal activation, a mean value of 18.0 hr ± 6 per cent was obtained; on vertical activation a mean of 36.2 hr; and on activation at an angle of 15 degrees a mean of 18.4 hr.[5] It would seem desirable in field use that the AC delay should be activated in a horizontal or downward position, following which its position could not be expected to have much influence on the timing. The reproducibility of these delays under such conditions of activation and use was remarkably good with the variance (see Section 9.11.2) being about 8 per cent.

In the interest of uniform performance between British and American production of the Mark I AC delay, producers in Britain and the United States both used the same source of celluloid disks. Some research was done in the division's central laboratory to discover a substitute for celluloid having improved qualities and being capable of better reproducibility in different batches. This work [3] was not particularly successful. American celluloid behaved very badly and was unreliable from batch to batch. Most plastics tried also had unfortunate characteristics such as sensitivity to humidity, brittleness, and so forth, which gave an excessive per cent variance. Of all the materials tried only butacite (polyvinyl butyral) appeared to be a possible competitor to well-cured celluloid. Should production of the AC delay be undertaken again in this country, it would be advisable to locate a suitable source of this material and give American production independence from British supply.

13.2.2 Short Time Mark I AC Delay [2]

From Table 1, it is apparent that the shortest timing for which the Mark I delay is suited is not expected to be less than 3 ½ hr even at a temperature of 86 F. For training purposes this was not satisfactory. It was desired that a shorter timing be provided so that men might familiarize themselves with the operation of the delay and still have the opportunity of seeing it function.

The division's central laboratory successfully met the problem by devising a new ampule solution and designing a new plastic disk to replace the celluloid.[2] A study of a variety of organic solvents disclosed that only methyl formate gave timings shorter than the Red timing quoted above in which acetone was the solvent. This timing was obtained most advantageously when the celluloid disk was replaced with cellulose acetate disks molded in an injection molding machine, through the courtesy of the Naval Ordnance laboratory at Silver Springs, Maryland. The resulting performance expected of the short time delay was as follows: at 32 F, 75 min; at 77 F, 35 min; at 112 F, 13 min. Variations of about 25 per cent could be expected. In spite of this rather high variance, the devices were useful for the intended training purposes but were never issued to the field.

13.2.3 Long Time Mark I AC Delay [4]

The need was expressed for a special operation requiring a delay period of several weeks. As will be seen from Table 1, the standard production of the Mark I delay could be expected to give a maximum timing of 9 days at 41 F. The central laboratory of the division therefore developed a new ampule solution for providing longer times. Table 2 gives the results of this work.

TABLE 2. Summary of timing data — long time AC Delay ampules.

	Composition in weight per cent				
Ampule designation	Dimethyl phthalate	*n*-butyl lactate	Temp	Mean value in weeks	Per cent spread
7	62.2	37.8	40 C	0.7	18
			25 C	1.8	24
8	83.4	16.6	40 C	1.5	20
			25 C	3.7	8
9	92.5	7.5	40 C	2.0	10
			25 C	5.6	11
10	99.0	1.0	40 C	2.6	7
			25 C	9.1	11

The above compositions were selected after a study of a variety of esters and mixtures of them. Since the operational requirement for the devices did not specify a very high degree of precision and performance timing, the considerable percentage variation was not felt to be a severe deficiency. The timings were obtained using the standard celluloid disk of the Mark I AC delay.

13.3 ORGANIC FIBER DELAYS

The search for a system independent of temperature and having good reproducibility included work on organic fibers. It seemed that nylon might be a likely choice since it could be made reproducibly in fibers of known diameter and was a pure chemical

substance. Also it was resistant to cold flow over periods of years while under a strain representing a large fraction of its breaking load. Tests with nylon, however, did not produce the hoped for results.

Work on other synthetic fibers of the regenerated cellulose type appeared more promising and is described in two parts of this section. While it was possible to construct a laboratory model of a delay based on these reproducible organic fibers, it was found that the timings provided by them were very greatly affected by a number of factors including the chemical composition of the solvent, the diameter of the fiber, the twist of the fiber, the per cent loading, and the area of the fiber under attack. In view of these tremendous complexities and the success which attended the Mark II development described in Chapter 10, the work was abandoned. It is felt that there is no promise in delays based on these systems, and they are recorded here to prevent wasteful repetition.

13.3.1 Nylon [7a, 8]

The solvent found most effective for nylon was unfortunately a 7 per cent nitric acid solution saturated with potassium nitrate, which attacked the nylon by its hydrolytic action on the amide linkages. The presence of the potassium nitrate gave a system which had essentially a zero temperature coefficient due to the high positive coefficient of solubility of the salt. Unfortunately, at low temperatures a slush of crystals formed by the deposition of nitrate tended to prevent contact with the nylon cord and gave extremely variable results. It was found also that variations in timings were very large for small variations in filament diameter, so that a 20-mil nylon wire was many times more resistant than a strong nylon cord of the same diameter composed of 306 individual filaments.

The only other solvent for nylon appeared to be a methyl alcohol solution containing 20 per cent of calcium chloride. This system did not have the very low temperature coefficient of the nitric acid system, although it did provide longer timings.

Another drawback to the nitric acid system, aside from the difficulty of handling such a strong chemical in the field, was its inability to provide a maximum timing of longer than about 20 min. This did not begin to cover the range of the Mark I Pencil. It was one additional reason for the decision to abandon nylon. Table 3 illustrates the performance which was obtained.

Table 3. Performance of nylon cord 8Z 7.1S.

Nylon cord	Solvent	Breaking time in minutes 2 C	26 C	60 C
8Z7.1S	25% HNO_3	11	5.3	0.2
"	25% HNO_3 Saturated with KNO_3	34	8.2	1.3
"	10% HNO_3 Saturated with KNO_3	9	10	5
"	7% HNO_3 Saturated with KNO_3	12	11.6	7

The remarkable effectiveness of the added potassium nitrate is clearly seen from Table 3. With it a temperature coefficient approaching zero would be unobtainable.

13.3.2 Cordura [7a, 8]

It was found that a high tenacity regenerated cellulose fiber woven in cords and known as Cordura was susceptible to attack by sodium hydroxide solutions with essentially zero temperature coefficient. This remarkable happening appeared to be the result of at least two competing chemical reactions which were not explored.

The fiber was a standard production item and as used was two-ply, had a twist and ply of 10.5Z; 7.5S, a tenacity of 36½ lb, and a 10 per cent elongation. When such a fiber was loaded to 30 per cent of its breaking load and immersed in a solution of sodium hydroxide varying between 4.2 and 5.2 per cent, a near zero coefficient resulted at 10 and 20 min breaking times. This ideal state was apparently reliable only with the conditions given, for a variation in one per cent of sodium hydroxide gave serious variations in timings and a complete loss of the zero temperature coefficient. Moreover, performance was very sensitive to the per cent loading, and since Cordura showed a tendency to elongation on standing under stress, a variable per cent loading was inevitable. Finally, it was not possible to alter the timing by dilution of the sodium hydroxide solutions. Added sodium chloride and glycerol or similar diluents, while somewhat effective in this way gave variable results, and it appeared that no timing of more than 40 min could be expected from the system. Also, the effect of twist was found to be considerable, but not of a nature to correct any of the deficiencies noted above. The substitution for sodium hydroxide by other chemicals such as potassium hydroxide, lithium hydroxide, and tetramethyl ammonium hydroxide was also ineffective.

For the many reasons given, the system was abandoned. Typical of the data obtained is Figure 1. Even had the system been usable, the problem would have existed of finding a suitable ampule to contain the strong alkali over indefinite storage. This appeared possible in the use of special Corning alkali resistant glass. It can be seen that the area bounded roughly by 32 and 35 per cent breaking load and 8 to 15 min in time had essentially a reliable performance independent of temperature.

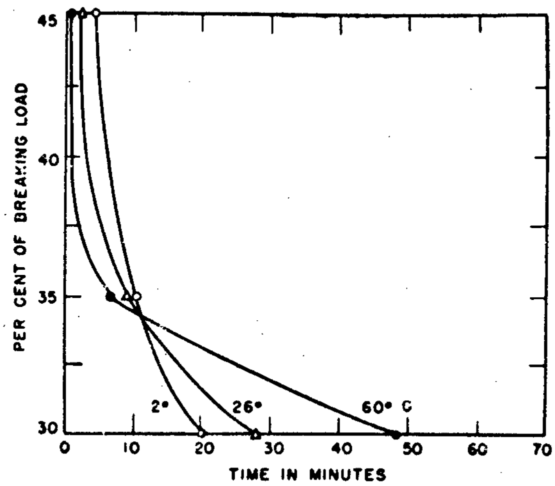

FIGURE 1. Effect of loading on breaking time for Cordura in 5.2 per cent sodium hydroxide.

13.3.3 Fiber G [7a]

This material differed from Cordura only in the method of manufacture. Tests with it gave better reproducibility at high times but poorer at low times. It also was entirely comparable to Cordura in possessing a zero temperature coefficient in a limited range and having great sensitivity to the numerous variables already mentioned. Figure 2 indicates the relationship between breaking time and loading time for this material in the best solvent, namely 10 per cent sodium hydroxide.

13.4 MAGNESIUM ALLOY DELAYS [9]

13.4.1 The Alloy

It seemed possible that a suitable alloy of magnesium might be discovered which would be stable under atmospheric humidity but which would spontaneously dissolve in the presence of an electrolyte. This was based upon the functioning of the alloy as a couple, in which the elements of an electrochemical cell were present. In some respects it resembled closely the idea underlying the Electrolytic Arming Disk (see Section 8.4.2) and the Mark II Pencil (see Chapter 10).

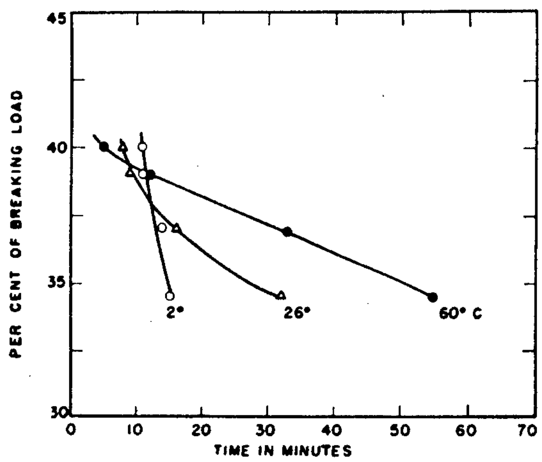

FIGURE 2. Effect of loading on breaking time for fiber G in 10 per cent sodium hydroxide.

From the laboratories of the Aluminum Company of America, a material was obtained which had these properties and consisted of: magnesium, 99.7 per cent; iron, 0.2 per cent; and nickle, 0.1 per cent. The fundamental process of all devices based on this alloy was the controlled corrosion of it by the electrolyte comprised of salts in aqueous solution. A number of salts were investigated of which ammonium chloride appeared to show the greatest advantage. This was explained by the following equations:

$$Mg + 2HOH \rightarrow Mg(OH)_2 + H_2 \text{ and}$$
$$Mg(OH)_2 + 2NH_4Cl \rightarrow MgCl_2 + 2NH_4OH$$

Because magnesium hydroxide is a stronger base than ammonium hydroxide the second reaction took place and the insoluble magnesium hydroxide which would otherwise accumulate was removed from the reaction exposing fresh surfaces for further attack.

Other considerations would indicate that, in either strongly acid or strongly basic solutions, magnesium would be too reactive and the reaction would tend to have a high temperature coefficient. The pH range provided by ammonium chloride was the most favorable which could be found. Using this metal and this system as the basis, two types of delays were explored to a point which indicated that neither would be likely to yield a successful competitor to the

Mark I or the Mark II Pencil. These types are given in the two following sections.

13.1.2 Barrier or Disk Type

In this application the electrolytic solution was brought into contact with the timing element of magnesium alloy which was in the form of a disk or a barrier separating the electrolyte from a dry add-water type of electrolytic cell. If the barrier disk of special alloy were of a predetermined thickness and had a predetermined exposed area, the time required for errosion of this disk was found to be fairly constant. Eating away of the barrier allowed the excess electrolyte to penetrate into the underlying electrolytic cell, of which magnesium served as the anode and a silver wire coated with a thin layer of a fused silver chloride served as the cathode. When contact was established, a current was produced by this cell which was sufficient to fire an electric squib (Hercules Blasting Cap 100-24B). Such a cell could be counted upon to deliver for a period of one min at a resistance of one ohm between 600 and 350 ma of current at 1.86 volts.

Several different designs were built utilizing this electric firing system, and of them the most successful contained the ampule of ammonium chloride solution in a gas-tight chamber with crushing provided in the manner of the AC delay (see Section 13.2). It will be noticed that hydrogen is evolved by the reaction and use was made of this to build up pressure in the gas-tight chamber and to provide a positive means of forcing the electrolyte through the eroded barrier onto the poles of the firing cell. No design was ever successful in providing operation independent of position and, from a field view point, this was so serious that the system was abandoned. It appeared also that unless the electrolyte was delivered to the firing cell instantly, the serious drain on that cell's potential gave frequent misfires.

Other considerations also led to the abandonment of the idea which is illustrated in Figure 3.

13.1.3 Shear or Tension Type

Much simpler than the barrier type were models based on the use of the special alloy as a wire, mounted either in shear or in tension, supporting mechanically a firing pin held against a compressed spring. The similarity to the Pencil time delay will be apparent. Figure 4 illustrates this type of design.

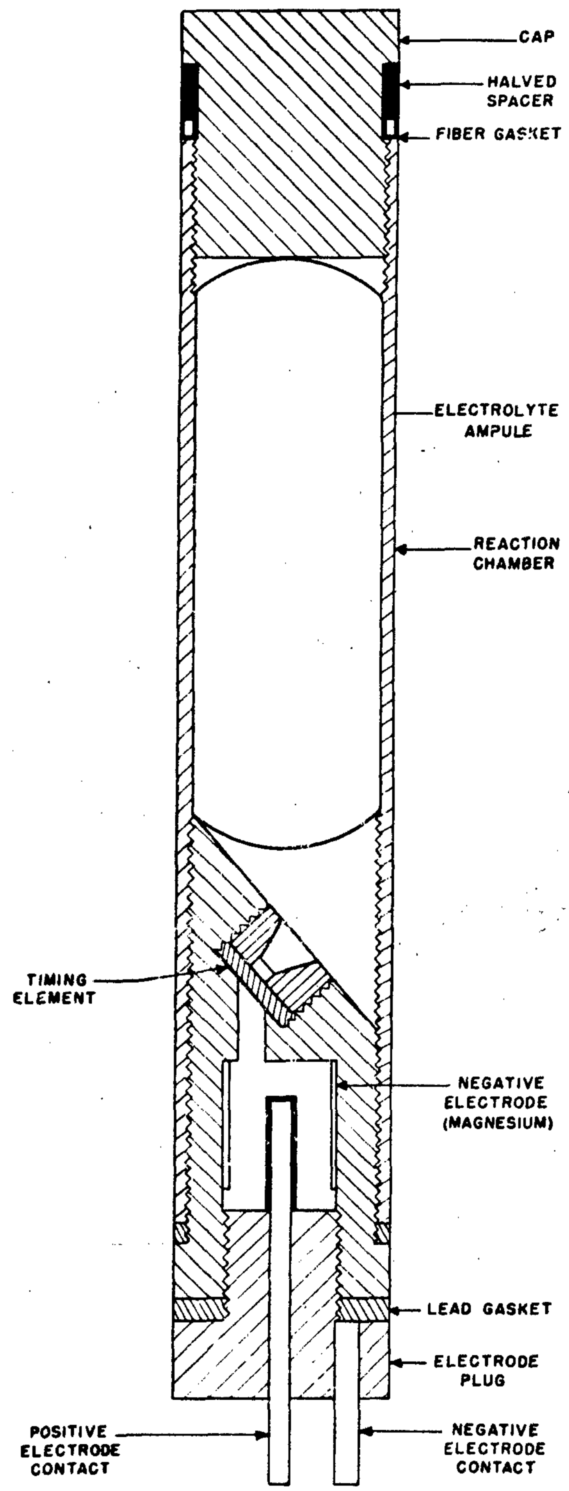

FIGURE 3. Barrier type magnesium alloy delay.

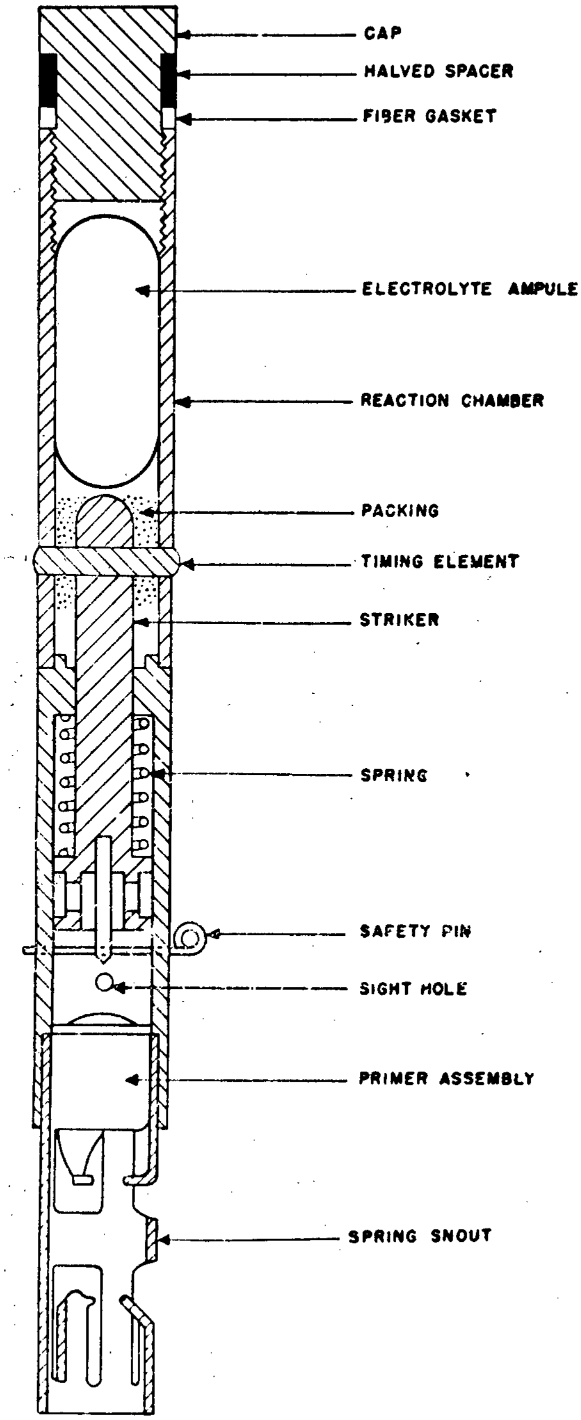

FIGURE 4. Shear type magnesium alloy delay.

In this model the deficiencies of the electric method of firing were eliminated but new difficulties arose in assuring that the alloy member was adequately bathed by fresh electrolyte solution during the reaction period and in using magnesium wires of diameter sufficient to prevent cold flow on long standing, while still being small enough to give useful time delay periods. The per cent variation expected from such a system was somewhere between 6 and 13, a distinct improvement over the Mark I Pencil; nevertheless, the design was one which would operate only in a vertical position, which would be very critical to manufacturing procedures (particularly to the diameter and dimensions of the stressed magnesium element), and which would show no remarkable advantages. Its performance is illustrated in Table 4 using an alloy shear pin of diameter 0.065 to 0.066 in. and 0.20 ml of electrolyte solution, one molar in acetic acid, sodium acetate, and ammonium chloride.

TABLE 4. Operational characteristics of shear type.

Temperature	Mean time	% Deviation
39 C	140 min	10.7
24 C	227 min	13.7
16 C	385 min	9.3
6 C	561 min	8.7
-2 C	559 min	6.3

These figures illustrate the increasingly good performance at low temperatures and, on the whole, remarkable independence of the essentially chemical reaction from temperature. In spite of these good features, the system did not have sufficient merit to warrant its serious consideration as a universal time delay comparable to the time Pencil. However, for very special uses where lightness and compactness are important features, a delay could be devised in which the special magnesium alloy might have great advantage over any other known system. Details of such a delay were worked out but it was never put into production.[1]

13.5 UNEXPLORED OR UNSUCCESSFUL SYSTEMS

A number of ideas came to the attention of the division. Many of them were never worked upon, and others were only partly investigated. They are recorded here as possibilities for future evaluation.

1. *Bimetallic Electrolysis.* A system was proposed consisting of two elements of cadmium and zinc respectively. Upon the addition of an electrolyte the spontaneous solution of the zinc might be useful as

the basis of a time delay. This was not investigated in view of the success of a similar system in the Mark II Pencil.

2. *Cold Flow of Metals.* Some work was done in the United Kingdom and by the division [9] on zinc and lead employed as metal sheets through which a striker point was caused to penetrate by spring action. A time delay system could thus be devised depending upon the force of the spring and the thickness of the metal sheet. Unfortunately both lead and zinc displayed an extreme sensitivity to temperature and shock and the system was abandoned.

3. *Gas Leak.*[10] Considerable work was done in Britain on a device consisting of an evacuated chamber sealed from the air by a metal tear strip cover, beneath which lay a ceramic disk of unglazed porcelain. The other end of the evacuated chamber was provided with a click diaphragm similar to that used in the Sympathetic Fuze (see Chapter 8). Removal of the metal cover allowed the atmosphere to flow through the pores to the ceramic disk and eventually to build up the pressure inside the evacuated chamber to a point where the sensitive bimetallic disk would snap and fire. Basically the system was sound in that the laws governing diffusion are practically independent of the ordinary temperature range; however, manufacturing difficulties were very severe and the problem of reproducing porous plugs was never overcome.

4. *Liquid Leak.* The use of constant viscosity liquids such as silicone flowing through minute orifices could be used as a basis for a time delay either mechanical or electric. Some work of this sort has already been mentioned (see Section 8.4.3) as a general scheme for a number of delays covering a wide range of timings.

5. *Swelling of Rubber.* It was found possible to devise a very inaccurate but certain delay based on the well-known property which rubber has of swelling when immersed in organic liquids such as gasoline. For special operational uses such a system was recommended.

6. *Battery Exhaustion.* It was suggested that a striker held by an electromagnet would fire upon exhaustion of the battery supplying energy to that magnet. The well-known variations in batteries and their extreme sensitivity to age and temperature made the system seem unlikely.

7. *Diurnal Temperature Change.* For a delay of one or more days, use could be made of the uncertain but inevitable temperature change which generally occurs with sunset. This type of delay would be very crude and limited to special uses in special geographical locations.

Much energy and several years of work were expended by division personnel in a search for an improved time Pencil and for new time delays in general. Those which were successfully developed were the Mark II Pencil, the improved Mark I Pencil, the clockwork delays, and the modified AC Delays. None of the systems given immediately above can in the opinion of the writer compete with these.

Chapter 14

RADIO-CONTROLLED SWITCH

14.1 INTRODUCTION

At the request of OSS and with the cooperation of the Signal Corps, Division 19 embarked on a program to develop a radio-controlled switch for the remote activation of explosive or incendiary materials.

The first operational requirement suggested that the switch be operated on a frequency close to 100 kc by a fixed radio station. It was required also that the switch have a maximum life after being planted and activated, which meant a design imposing only a small drain on the dry cell batteries which would be required to keep the set in operation. Secondly, it was desired that when these batteries had exhausted themselves and the set was no longer able to function on receiving the appropriate radio signal, it should automatically destroy itself. A third major requirement called for mechanical firing to be accomplished upon receipt of the proper signal, but only after an interval of sufficient duration to prevent the accidental tripping of the switch by enemy sweeping of the air or by accidental natural disturbances (Section 14.2).

A switch meeting these requirements had reached an advanced state of development when the operational picture altered and the need for a set operated on 100 kc vanished. In its place appeared a need for a radio switch to function on receipt of a signal of about 100 megacycles. Transmitting equipment capable of providing this signal existed in all standard bombers of the United States and Great Britain, and operations were visualized in which radio switches previously planted by ground forces would be activated by on-coming bombers when they were close to their target. On activation the switches would fire flares, which would mark the target more precisely or delineate the front line of operations, thus preventing accidental and premature dropping of bombs on friendly troops. Another use conceived for such a switch included the marking of air fields at night (Section 14.3).

The last phases of the program were concerned with the development of a similar switch to be operated by a transmitter on the ground in a range of 3 to 8 megacycles. Such a switch would be of interest to the Corps of Engineers and could be used to detonate explosives planted prior to a retreat (Section 14.4).

The problem was not unique with Division 19, for the Signal Corps had similar devices under development and some of them in production and use. The work was not entirely repetitious, however, because of the tremendous effort made to keep volume and weight of the radio switch to an absolute minimum, and to provide the longest possible shelf life and self-destructive features. Since the personnel of Division 19 were not by background equipped to deal adequately with a radio problem, the bulk of the work was very generously done in Division 13 with the aid of a cooperative committee comprising the two divisions and the interested liaison officers.

The only one of this family of switches which was produced was the one to be operated by aircraft at 100 megacycles, of which approximately 1,000 units were manufactured by OSS.

14.2 OPERATION AT 100 KILOCYCLES[1]

This unit consisted essentially of a loop, a metal housing for a radio chassis relay, a battery pack, an electrolytic cell, and a self-destructive mechanism. The block diagram shown in Figure 1 illustrates the operational scheme.

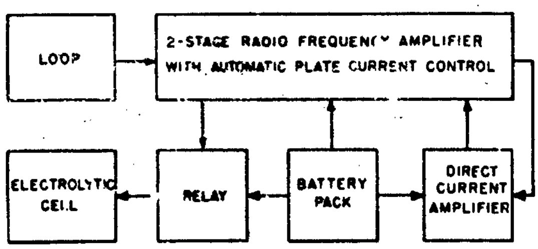

FIGURE 1. Block diagram of operational scheme, SE unit.

The receiver unit was cased in a sealed box having a volume of 216 cu in. and carried an insulated loop measuring 6 x 9 x 1/16 in. attached by clips. Of the total volume, nearly one-half was provided for the electrolytic cell and its accompanying mechanical detonating train and a charge of plastic explosive or incendiary material. The loop tuned to the operating carrier frequency of the transmitter when located in a field strength of 100 microvolts per meter or more applied a voltage on the grid of the first radio frequency amplifier stage. Another stage following this increased the amplitude sufficiently to reduce the bias on a direct current amplifier, thus causing plate cur-

rent to flow in an output resistor. So long as this was low, the B battery current passing through a relay coil kept the relay armature open, but as soon as the field strength reached 100 microvolts per meter the current passing through the relay coil increased to the point where the relay armature closed. Closure of this connected a battery circuit involving the so-called electrolytic cell. This was provided to prevent premature firing of the switch by accidental signaling. So long as a constant signal of the proper wave length and field intensity was received by the loop, a current would pass in the electrolytic cell, eventually operating it.

This cell consisted of a thin glass bulb filled with dilute sulfuric acid and containing two platinum electrodes. It was mounted in two bayonet-type sockets under a tension of 8 lb and was an integral part of a mechanical firing train. Passage of the electric current through the cell resulted in the electrolysis of the dilute acid with the production of hydrogen and oxygen gas. Collection of this continued in the glass bulb to the breaking point, whereupon the mechanical initiating system of the device operated and the charge was fired. The exact performance of the electrolytic cell depended on the temperature, the diameter of the bulb, and more critically on the diameter of a bubble of air sealed in the cell in its manufacture. In Figure 2 [11] the performance obtained as a function of temperature and bubble diameter is recorded.

It is apparent, for example, that with a bulb having a bubble diameter of 1/8 in. at 74 F receipt of the proper signal for 5 min would be required before the switch would perform. In this way complete safety was provided against accidental triggering by enemy or natural means.

Should the small battery pack of the radio switch become exhausted prior to receipt of the proper signal, the B and filament voltages would drop sufficiently on the amplifier tubes to allow the relay armature to close as before, bringing about the self-destruction of the unit. Tests with this type of switch showed that it would operate over a distance of at least 30 miles provided it were not shielded by large metal objects. The ambient field strength could be safely estimated by a user in advance and the device adjusted so that arming it did not entail danger. Furthermore, adjustments could be made in individual

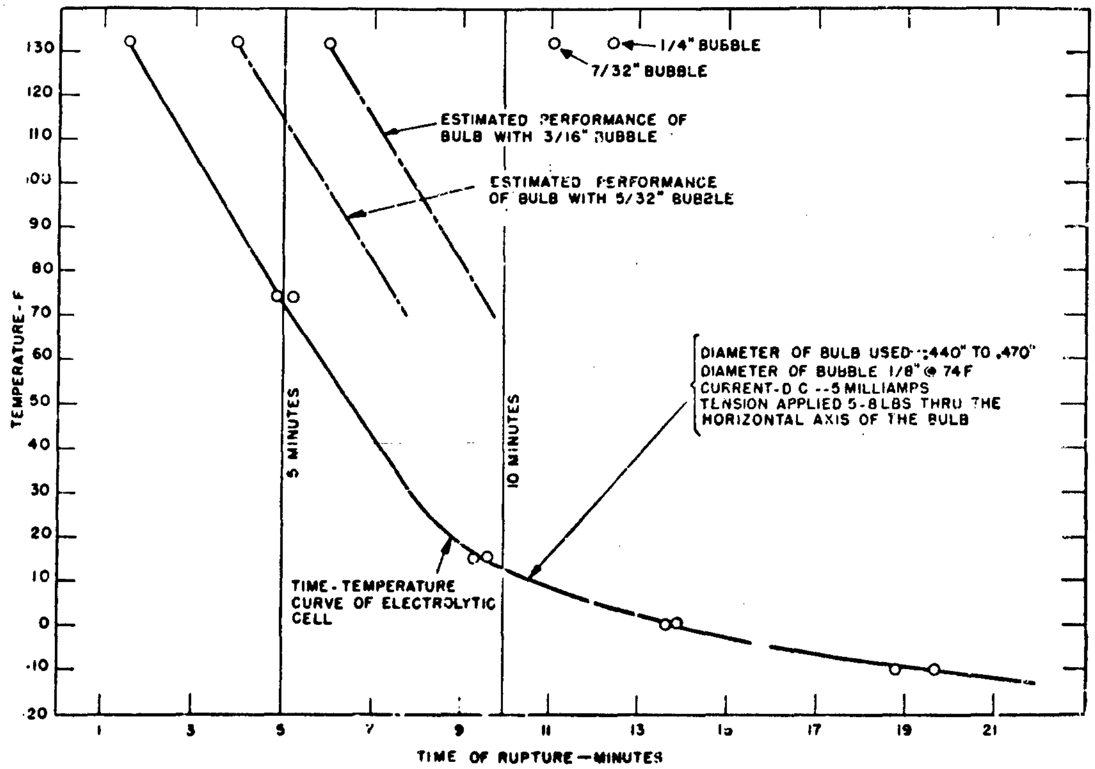

FIGURE 2. Performance of special electrolytic cells at various temperatures.

sets to provide functioning between 95 and 120 kc with increase in sensitivity and decrease in selectivity at the higher figures. A total weight of 8 lb, including 2 lb of batteries, gave a switch having a life after planting of approximately one week.

11.3 OPERATION AT 100 MEGACYCLES [9]

11.3.1 Single Tube Model

Using a proposal of a circuit containing a super-regenerative gas tube such as had been used for the control of model airplanes in flight (triode type QF-6), a circuit was designed operating at about 90 megacycles.[10] Using the single tube and very small batteries, it was believed that a unit occupying not more than 18 cu in. and having an operating life of about one week could be devised. This would be a great improvement over the rather bulky 100-kc model and, moreover, would more closely approach field requirements. Unfortunately, attempts to construct a switch based on this single QF-6 tube were entirely unsuccessful due to the breakdown of the tube under the conditions imposed by operation at frequencies close to 100 megacycles. It appeared that the QF-6 had been designed primarily for use at 60 megacycles.

Attempts to develop a new tube which would suffice for the higher frequency ranges were unsuccessful, and the early designs were abandoned.[2, 3, 4] This was not before it had been discovered that changes in sensitivity could be caused by surrounding objects due to absorption, reflection, and radiation and that there were limitations in the mechanical and electrical components. Notable among these was the requirement of delayed action, which in the 100-kc model had been met by the electrolytic cell. This was not considered feasible for use with the 100-megacycle unit because of its fragility and irreversibility.

The suggestion that the armature of the relay be of a pendulum type suspended in a vertical position, so that its time cycle would be sufficient to cause it to be inactive during momentary electrical impulses did not on trial prove satisfactory. Moreover, it imposed a positioning of the switch, which was not felt desirable. On the other hand, a delay provided by a meter type movement was found to be quite practical, insensitive to vibration, and, when provided with magnetic damping, unresponsive to a plate current caused by static surge in the neighborhood of ½ sec, a period which should have been ample to take care of any such accidental interference.

The switch was also provided with a booby-trap arrangement to prevent its being moved, and arming was accomplished by the use of a special key which would be disposed of by the operator. Any attempt to interfere with the set by the insertion of a substitute key would result in instantaneous operation, since an electric contact directly to a small internal charge of plastic explosive would thereby be made. Operation of the set on exhaustion of the batteries was as described in the earlier devices.

Even though the one-cell model based on the QF-6 tube proved impractical, it nevertheless contributed features to the later successful design.[5]

The circuit of this switch is shown in Figure 3. Although only a single tube was used, operation of the circuit was complex. It functioned simultaneously as a self-quenching super-regenerative detector and as an audio-frequency gas tube relaxation oscillator. Upon receipt of a signal of proper frequency and intensity, the plate current dropped to a fraction of its normal value, causing the relay to close the external circuit.

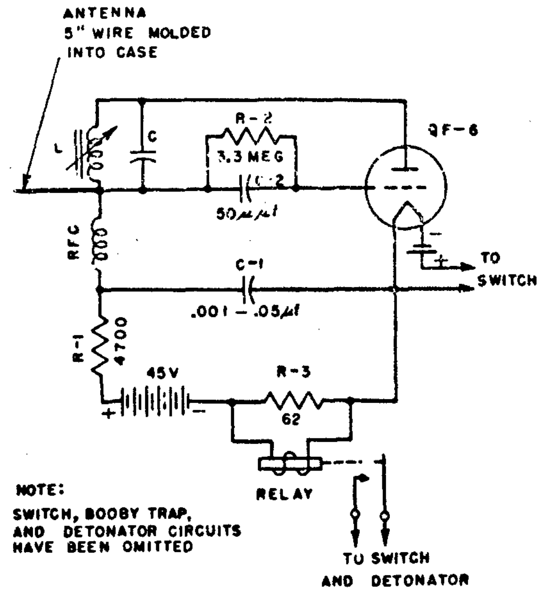

FIGURE 3. Circuit diagram of radio-controlled switch.

11.3.2 Two-Tube Model

When it became evident that the circuit mentioned above would not be satisfactory, consideration was given to one employing other types of tubes. A new circuit was designed to operate on an r-f carrier which was amplitude-modulated with an audio tone of predetermined frequency. It would thus not operate on

an unmodulated carrier, and the audio-frequency selective circuit and time delay carried in the switch made false operation unlikely. Models of this type having a volume of about 60 cu in. and weighing about $2\frac{3}{4}$ lb, including batteries, had sufficient sensitivity to be operated by an SCR-522 transmitter from a plane at an altitude of 10,000 ft, 10 miles away. The essential circuit of this switch is shown in Figure 4.

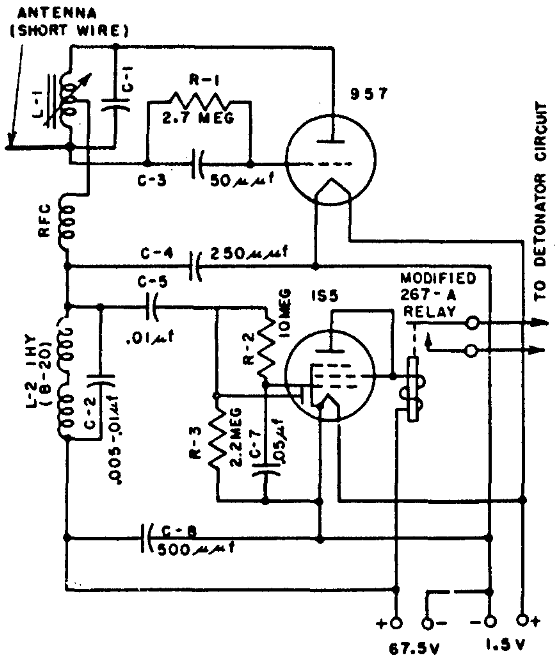

FIGURE 4. Circuit diagram of two-tubed radio-controlled switch.

Two tubes were employed: a type 957 super-regenerative detector, and a type 1S5 having both a diode and pentode section. The diode was used to rectify the audio-output voltage from the detector. The direct current voltage so obtained biased the grid of the pentode section negatively and reduced the current in the plate circuit materially, thus the relay normally held was released upon the receipt of the tone-modulated control signal.

Because the detector load impedence was an antiresonant circuit, operation of the switch depended upon a prescribed narrow range of audio-frequencies. In this feature lay the safety of the circuit. In addition, the network provided against false operation by giving a delay of about 250 millisec. Operated at an ambient temperature of 70 F, this circuit had a maximum life of approximately 80 hours. Increase in battery load would, of course, increase this time.

Detection of the switch due to radiation from it was not easily accomplished, for it did not produce a characteristic whistle when the receiver frequency oscillator was turned on. The accuracy of tuning was about ± 100 kc, and, in view of the broad response characteristics of the switch, it was considered sufficient.

The theoretical range would depend upon the field intensity; where tuning was accurate, the switch operated on a signal of 200 microvolts per meter or less. Little or no attenuation due to surrounding objects would be expected. Table 1 gives the performance from planes at different altitudes.

TABLE 1. Performance of two-tube model at various altitudes.[5]

Altitude feet	Range — Miles: Reliable operation (500 mv/m)		Possible operation (200 mv/m)	
	Dry soil	Moist soil	Dry soil	Moist soil
1,000	$3\frac{1}{2}$	$4\frac{1}{2}$	6	9
5,000	$7\frac{1}{2}$	9	13	19
10,000	10	12	17	25
20,000	13	14	23	31

11.3.3 Aircraft Modulating Unit[6]

The radio-controlled electric switch described in Section 11.3.2 operated from a tone-modulated signal of predetermined audio-frequency from a transmitter standard in bomber planes (SCR-522). A circuit was required to provide the tone modulation at the transmitter. Two models of this circuit were made and tested. They were not, however, put into production because of the lateness of their development.

These two models had the same circuit, which differed in the method employed to secure alignment with the audio-frequency to which the frequency was tuned. Model 1 was a stable fixed-frequency model, while Model 2 had its frequency continually varied over a range of ±85 c at the rate of 3 times per minute by means of a motor-driven condenser. The latter system was more flexible and did not require rigid adjustment of the set and the modulating unit. Either unit was portable, operated from dry batteries, and arranged to plug into the interphone system in place of one of the regular microphones. Functioning depended upon adequate insulation of the unit from extreme cold.

14.4 OPERATION AT 10 MEGACYCLES[7]

It was determined that a practical switch small enough to fulfill tactical requirements could be developed operating in a frequency range of 3 to 8 megacycles, provided by a standard CW ground transmitter used by OSS and based on the SCR-536 Handy-Talky. A five-tube switch circuit using a 39-in. vertical whip antenna was suggested which would meet most of the specified requirements including an operating life of 36 hours and a range of approximately 3 miles. The usual requirements of self-destruction upon exhaustion of the battery or upon attempted interference were included.

The complete circuit comprised a converter, an intermediate frequency amplifier, a detector, an audio-frequency amplifier, a limiter, and a rectifier. The circuit following the limiter was similar to the 1S5 tube rectifier-amplifier and relay employed in the 100 megacycle switch (Section 14.3.2). The frequency was accurately established by a crystal oscillator.

Operation was provided by a field strength of 40 to 150 microvolts per meter and for protection against false operation on interfering signals or noise, an audio-frequency selective circuit tuned to 100 c and preceded by the limiter to reduce the effect of variation in signal strength was suggested. A time delay of 10 sec or more could be incorporated as an added safeguard. Figure 5 presents the significant part of the circuit of this device.

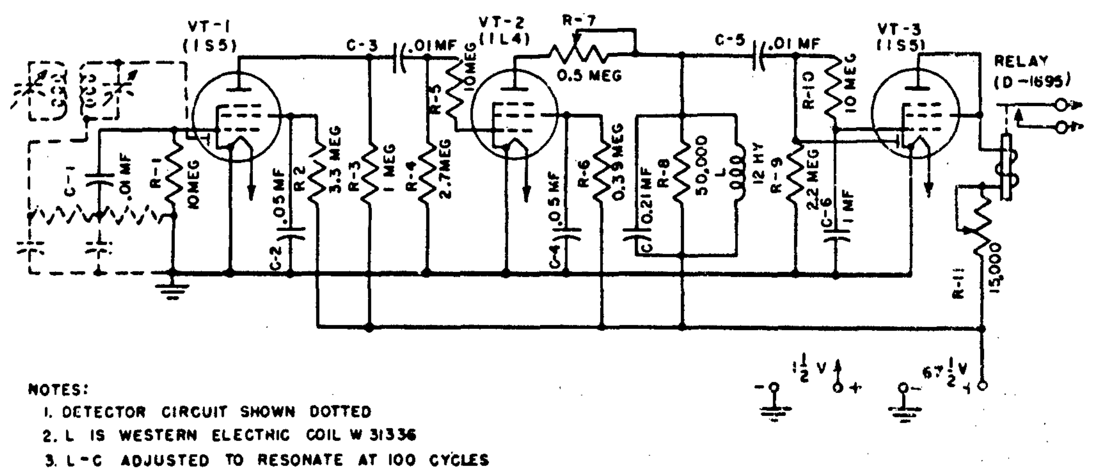

FIGURE 5. Circuit diagram of audio-frequency section of radio-controlled switch.

PART III

COMMUNICATION DEVICES

In this part of the Summary Technical Report of Division 19 are described a number of developments which did not reach completion prior to the termination of the division's activities. They are all concerned with various types of secret communications over relatively short distances, ranging between a few feet and two or three hundred yards. The medium of communication was in some cases air and in others water. In every case, however, the object was to allow individuals, presumably on reconnaissance missions, to communicate with great security with each other either by telegraphy or by voice. The systems on which the devices were based were, therefore, those which rapidly attenuated with distance and which do not lend themselves to development to very great range. In Chapter 15 will be found the details of a system based on the induction field. Two devices are described, one the IFT, which was both a receiver and transmitter, and the other an IFL, which was a transmitter alone. Operationally the IFT's were considered useful for communication in jungle terrain by a reconnaissance patrol and for the location and direction of members of the party. The IFL was useful in the European theater as a homing device on which the various members of a parachute stick could locate themselves after parachute landing. Both of the devices allowed this type of operation because of their directional effect. They are the only ones of the devices described in this part which were produced in quantity and were of special interest to the Signal Corps and the Airborne Command.

Chapter 16 describes various means of communication through water. The operational use was of two kinds. In the first, communication across rivers or harbors or between craft and shore would be possible. In other applications communication between swimmers or operators of underwater craft would be achieved and in this case could be either telegraphic or telephonic. A few models of the devices known as the UWT were produced and successfully demonstrated but the system was not fully explored.

In Chapter 17 are described some miscellaneous devices based on supersonic communication and a microwave transmitter-receiver known as the MWT. These devices were even less perfectly developed and are recorded here to preserve the information acquired. In common with all the other parts of this volume, the contents of Part III are designed primarily for the individual operating alone or in a small party close to enemy lines and in a most clandestine manner. It is believed the devices will interest Army Ground Forces and the Signal Corps as well as the Navy and the Marine Corps.

Chapter 15

A SHORT RANGE INDUCTION–FIELD COMMUNICATING SYSTEM (IFT–IFL)

15.1 INTRODUCTION

In April 1943, several requests were submitted to Division 19 for short range secret signaling systems. The OSS and the Marine Corps described several situations for which a communicating system, with a range of about 100 yd that would not be detectable by the enemy at distances greater than 200 yd, was desired. To meet this demand the *induction-field transceiver* (IFT) was developed for two-way communication at distances up to 125 yd and the *induction-field locator* (IFL) was developed to emit automatically signals that could be received at distances up to 100 yd by means of an IFT.

The induction field was used as a means of communication because the strength of the signal decreases approximately as the cube of the distance from the transmitter. Thus a properly designed transmitter and receiver could be used at the desired range; at distances only a few yards beyond this desired range, the signal would be undetectable by enemy observers. The apparatus was developed to satisfy these criteria and to have minimum weight and volume consistent with an adequately rugged structure.

The latest model of the IFT (Model B12),[1] constructed in the laboratory in 1944 and produced in small quantities by a subcontractor in 1945, comprised a metal case which could be attached to the belt of the operator, a coil which was strapped on his back, and an earphone which could be attached beneath a helmet. The total weight of the transceiver was approximately 2.5 lb.

The most recent model of the IFL (Model B8) [1a] consisted of a single case into which the electronic equipment was assembled; the coil which produced the induction field was mounted around this equipment. The weight was approximately 2.5 lb and the size was 6½ x 5 x 1⅝ in. This instrument was also produced in small quantities early in 1945.

Two or more operators, each carrying an IFT were able to communicate by coded signals at distances up to 125 yd. Because of the directional properties of the apparatus and the field which it produces, it was found possible for the operators of these devices to approach each other simply by listening to the coded signal from the other transmitter and by walking in such a manner that the signal strength increased. The IFL, put into operation by means of a switch on the device, transmitted a continuous signal for about 16 hours. During this period an operator equipped with an IFT could locate the IFL if it were within 100 yd of him by walking in the direction that gave rise to an increased signal. Beyond approximately 200 yd, signals from the IFT and the IFL were inaudible on the receiving apparatus of the IFT and were thought to be inaudible by an enemy using any of the known scanning radio receivers.

The following sections are devoted to a description of the IFT and IFL and to a description of tests of these devices.

15.2 MODEL B12 IFT AND MODEL B8 IFL

A coil carrying an alternating current sets up an electromagnetic field. The mathematical analysis of this field suggests that it be described as a combination of two fields, an induction field and a radiation field. As the frequency of the current of the coil is increased, the distance from the transmitter at which the induction-field intensity and the radiation-field intensity are equal decreases; this distance is equal to the wavelength (corresponding to the frequency of the current) divided by 2π. Thus, in the case of an alternating current of 50,000 c, the radiation field and the induction field are equal at a distance of approximately 1,000 yd from the transmitter; and at higher frequencies, this distance is less.

For a given current in the induction-field coil and for a given distance of separation of transmitter and receiver the received signal voltage increases linearly with ~~the~~ frequency.

Therefore, if the induction field is to be used as a means of transmission, the frequency should be high in order to attain high sensitivity and the frequency should be low in order to achieve security. After experimenting with induction-field transmitters and receivers over a range from 3,000 to 60,000 c, it was decided to choose a frequency of 50,000 c as a suitable compromise for the requirements in this problem. Frequencies less than 20,000 c have the advantage of

increased security, but the apparatus for the low frequencies is excessively heavy and bulky.

The major part of the development which led to the production of the Model B12 IFT was concerned with the problem of constructing from available components a compact, lightweight, transmitter and receiver of 50,000 c induction-field signals. Many different types of tubes and different kinds of batteries were tried and extensive experiments were made to determine the optimum design of a coil for the transmission and reception of the signals.

The resulting Model B12 IFT comprised a transmitting and receiving coil, a transmitter and receiver which together with batteries were included in an aluminum case, and an earphone. The aluminum case, which could be attached to a belt and supported in front of the operator, was 7 in. long, 4½ in. wide and 1⁵⁄₁₆ in. thick. The device was worn so that one of the ends 4½ in. by 1⁵⁄₁₆ in. was upward, the case being held flat against the body. In this upper end there were mounted a push button for sending coded signals, and combination volume control and an on-off switch. Cable terminals for the induction-field coil and for the earphone were also mounted in this case. Within the case there were four vacuum tubes, batteries, and other circuit components. The batteries were so arranged that they could be easily removed and replaced without the use of special tools. One of the tubes was used as an oscillator for transmission and as a 50-kc amplifier for receiving. A second tube was used as a local oscillator to produce 47.5 kc per sec and as a converter. The output of this tube was put through a low-pass filter from which the audio-frequency signal was fed into a two-stage audio-frequency amplifier and then into the earphone.

The induction-field coil consisted of 100 turns of number 27 wire, wound spider web fashion to reduce distributed capacitance. The coil was flat (17½ x 11¾ x ³⁄₁₆ in. thick). It was equipped with straps, so that it could be attached to the back of the operator, and carried a cable, the plug of which was inserted into the case of the transmitter-receiver.

The Q of the coil and cable was found to be approximately 75. A photograph of the entire apparatus is shown in Figure 1, and the apparatus within the case is shown in Figure 2.

In operation, two men equipped with the Model B12 IFT separated by a distance of about 100 yd turned on their devices and adjusted the volume controls to maximum. If operator A then pushed the transmit button of his device, the 50-kc oscillator

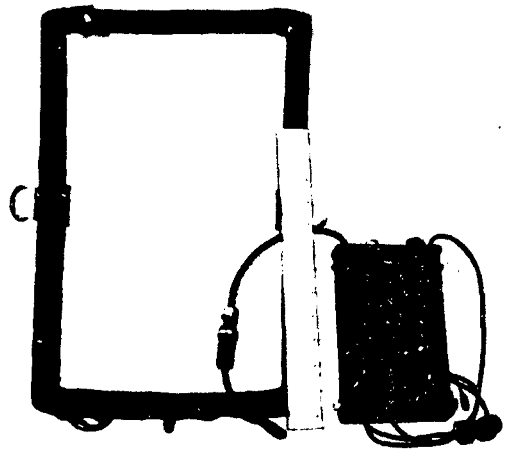

FIGURE 1. Model B12 IFT. (The electronic equipment and batteries are enclosed in the aluminum case at the right; at the bottom is the earphone; to the left is the induction-field coil which is strapped on the back of the operator.)

caused a current of this frequency to flow in the induction-field coil and thus set up an induction field surrounding him. Operator B would then hear a 2,500 cycle signal unless his coil were turned at right angles to the plane of the transmitting coil. The signal heard by operator B was caused by the voltage induced in his induction-field coil by the transmitted signal, the amplification of this signal by his first amplifier, the conversion of this signal to a 2,500 cycle audio-frequency signal by his converter, the amplification of this audio-frequency signal by the two audio-frequency stages, and the audible signal thereby produced in his earphone. The maximum signal strength occurred when the coils were coaxial. Thus, operator B could determine the line-of-sight to operator A by turning until the signal was maximum. He could then walk straight forward; if the signal strength increased, he was approaching operator A; if the signal strength decreased, he was walking away from operator A.

Figure 3 is the wiring diagram of the Model B12 IFT. Note that the tubes are Raytheon Hearing Aid tubes. With each instrument a brief instruction manual [2] was issued. This instruction manual described not only how to operate the device but also how to adjust it for optimum sensitivity and how to replace batteries.

The Model B8 IFL was a single tube transmitter

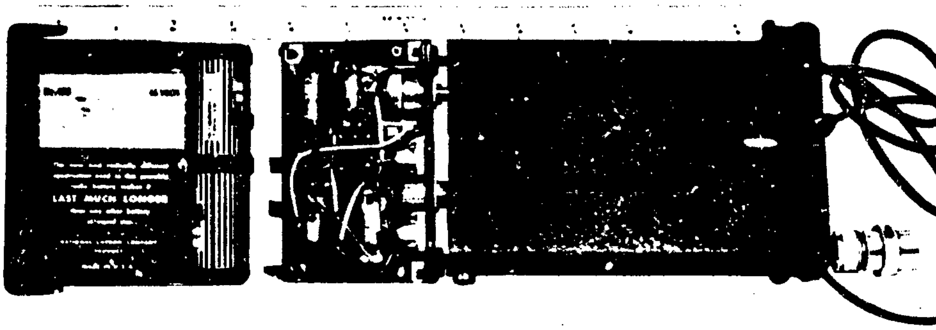

FIGURE 2. Chassis and battery holder removed from the case of Model B12 IFT.

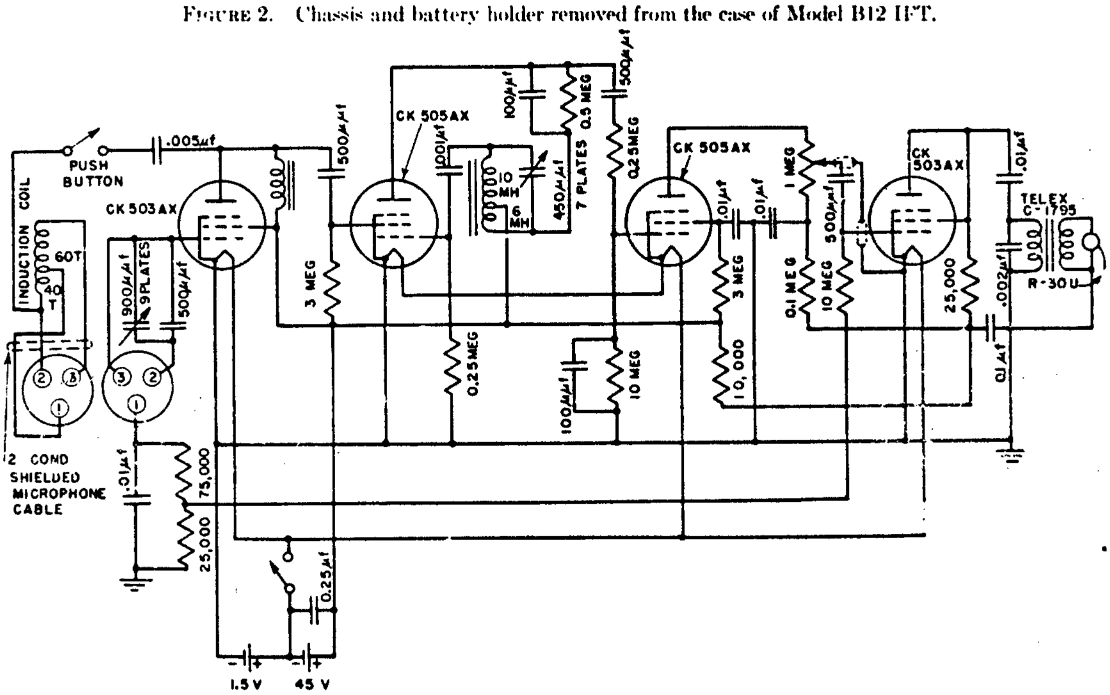

FIGURE 3. Circuit diagram of Model B12 IFT.

built into a case 5 x 6½ x 1⅝ in. on a circuit designed to oscillate at 50 kc. The coil wound around the edge of the case and within its outside cover served, not only as the inductance of the oscillator, but also as the producer of the induction field. The operator of an IFT, within a range up to about 100 yd could hear the signal from the IFL and could approach it in the same manner as that described above. Figure 4 is the wiring diagram of the Model B8 IFL. An instruction manual [3] for this device was issued with each such piece of apparatus.

15.3 TESTS OF THE IFT AND IFL

Extensive laboratory and field tests of the IFT and of the IFL were made in Philadelphia; in addition, several tests were conducted by various branches of the Services. Prior to these, early models of the IFT were subjected to a jungle test,[4] being exposed to tropical climate for several weeks. These tests showed that the apparatus as then designed was subject to fungus growth and deterioration so that it soon became inoperable. Subsequent models were designed

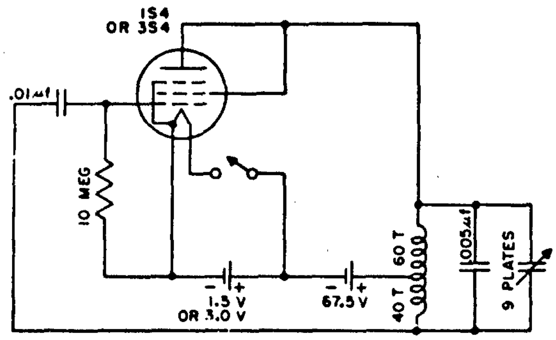

FIGURE 4. Circuit diagram of Model B8 IFL.

to minimize these effects; these later models, including the Model B12, were tropicalized, following Army recommendations for such procedures. The early models of the IFT tested in the jungle were found also to operate at a distance of only 50 yd through dense jungle undergrowth. This was the only report of a limitation of range due to vegetation. Subsequent tests of later models showed that the redesigned IFT operated satisfactorily at ranges of 100 to 125 yd under similar circumstances.

The Marine Corps tested several Model B4 IFT's and found the range of that model to be about 75 yd. They also found that it was possible to communicate using one IFT within a tank and another instrument outside.[5]

The Model B12 IFT and the Model B8 IFL were submitted to the Army Signal Corps for test at the Camp Coles Signal Laboratory.[6] Their report indicated a reduction in range in an acoustically noisy location, but the character and causes of this acoustical noise were not described by the observer. These tests also showed that, using a Type HRO receiver equipped with a loop, the IFT and the IFL could be heard at about 100 yd but not at greater range. This result confirmed the design criterion that the signals from the IFT and the IFL would be secure from enemy scanning. The Signal Corps testers placed the receiving IFT about 20 ft from each of several radio transmitters and found no reduction in range, that is, no interference was produced by transmitters having several frequencies from 1 megacycle per sec to 240 megacycles per sec and rated from a few watts to eight kw. As a result of these tests, the Signal Corps submitted a list of 19 specific recommendations for changing component parts of the B12 IFT in order to satisfy the specifications of the Armed Forces. The only basic design change was the suggestion that more audio-frequency amplification be provided to increase the output level when the IFT was used in a region where there was high-intensity ambient, acoustic noise.

Four field tests and demonstrations of the B12 IFT and the B8 IFL were organized in the European theater by an OSRD scientific advisor to the First Airborne Army, early in 1945.[7]

In these tests and demonstrations, the operation of the IFT and the IFL was explained to Army officers, and they were asked immediately to use the equipment for specific purposes. Thus, for example, an officer was told that an IFL was somewhere within 75 yd of him, and he was asked to find it using an IFT. In spite of the complete novelty of the devices to the users, the tests were successful; the IFL was found, even when buildings and natural obstacles intervened between the initial position of the observer and the IFL. In one case, as an officer with an IFT approached to within 20 yd of the IFL and stopped to adjust his volume control, the IFL was moved quickly to a position behind the observer. Having adjusted his volume control he proceeded in the direction he had initially taken and found that the signal strength decreased. During the next few seconds he decided that the IFT was not operating properly and then turned and walked in a different direction. He quickly found the IFL in its new location. Even under the most difficult conditions, the IFL was located within ten minutes or less. During these tests also, two operators using IFT's not only were able to find each other and to meet, but also arranged coded signals so that one operator could direct the other to proceed forward, turn left, turn right, and so forth. On the basis of these tests, rush orders for 3,600 Model B12 IFT's and 400 Model B8 IFL's were initiated. The first thousand items had been produced and shipped when the war in Europe ended.

It was noted in tests performed by NDRC that the presence of metal near the induction-field coil modified the frequency and decreased the range of communication. Thus, when an IFL was placed inside a steel railroad car, the range was about 50 yd when the IFL was near the center of the car, and was reduced to about 15 yd when the instrument was placed flat against the steel wall of the car. Furthermore, the presence of the metal caused the frequency to be increased by approximately 5 per cent. On the other hand, an IFL placed in an automobile (sedan) travelling 40 mph was heard for a period of one second by observers with IFT's 20 yd from the road along

which the car passed. Thus, although the presence of metal caused a decrease in range and an increase in frequency, it did not prevent the operation of the IFT or IFL. The Marine Corps tests mentioned above were consistent with these observations.

Early in 1945, a representative of the developing contractor was loaned to the Office of Field Service, OSRD to take several devices to the Southwest Pacific area for demonstration. From March 1945 to the beginning of June 1945 he demonstrated the IFT and the IFL to units of the Sixth Army and others. In his reports submitted to the Office of Field Service, he recorded the descriptions of these demonstrations. The general conclusions which he reached by summarizing the comments submitted to him by officers who attended the demonstrations indicated the need in that area for devices with greater range than the range of the IFT and IFL. It was the concensus of opinion of these observers also that communication of this kind should be by voice rather than by code; that the range should be about 400 yd; and that the need for security from enemy detection was not great.

It would appear that the IFT and IFL were designed according to criteria which were more satisfactory for tactics in the European theater, than in the Pacific theater. No further development of the IFT and IFL along the lines suggested by the officers in the Pacific theater was attempted because of the late date.

15.4 SUGGESTED CHANGES IN THE IFT AND IFL

As a result of field demonstrations, numerous suggestions were made for changing the IFT and IFL. These are listed in detail in a separate report,[1] but several of them are presented below.

It was recommended that the range be increased to 200 or 250 yd. It is unlikely that this can be done without greatly increasing the weight and volume of the apparatus. The particular characteristic of the induction field which makes it useful for this purpose also makes it necessary to use very high-power equipment to achieve ranges greater than about 125 yd.

It was suggested that the apparatus be redesigned to use voice transmission. This also would increase the weight of the equipment for the same range. Nevertheless, the use of voice is possible and could be investigated.

It was suggested that the frequency be changed to 100 kc. This frequency was initially avoided because it was thought to be within the range scanned by the enemy. No experiments were performed at this frequency, and theoretically, no great increase in range is to be expected at this frequency, but the experiments could easily be carried out if subsequent developments required them.

It was recommended that the IFT and IFL be designed to have several frequencies of transmission. This idea was tested by constructing two IFT's which could be operated at 40, 50, or 60 kc per sec. The volume of the apparatus was increased and the weight was increased by about two pounds. The equipment operated satisfactorily at all three frequencies. This procedure enabled an operator to communicate with each of three other operators who would not interfere with each other.

15.5 CONCLUSION

The use of the induction field for short-range communication was demonstrated to be an effective and useful method but the investigation was in no case carried to a complete conclusion since the devices were developed and produced for specific purposes. Thus there remains a field of investigation which might well bring out features of this mode of communication other than those which were included as the criteria for the development described herein. The work described here is believed to indicate clearly, however, that the induction field has possible value for military purposes.

Chapter 16

SHORT-RANGE COMMUNICATION BY MEANS OF LOW-FREQUENCY CURRENTS IN WATER

16.1 INTRODUCTION

It was requested that means be provided for intercommunication between ship and shore under conditions where security was extremely important. It was also suggested that a means of communication between a swimmer and a ship or another swimmer might be useful. Although no precise specifications were given, it was understood that the apparatus should have ranges varying from 200 to 2,500 yd, that the equipment should be as light in weight as possible, that it should operate satisfactorily at depths up to 100 ft, and that it should be as secure from enemy detection as possible. During the first stages of development, it was stated that code communication would be satisfactory, but it was later specified that transmission by voice would be more useful. Late in 1943 the suggestion was made that it might be possible to insert electrodes in sea water, to feed low-frequency currents into these electrodes, and to detect signals at some distance by another pair of electrodes inserted in the water; such a system was designated *underwater telegraph or telephone* [UWT]. By avoiding the use of radio signals, acoustic signals, infrared signals, and light, security was enhanced.

The initial approach to the problem consisted of a theoretical analysis of the propagation of electric currents in water and the design of electrodes for producing such currents and for picking up signals.[1] This analysis showed, not only that it would be possible to devise apparatus to communicate by means of currents in water, but also that the signals would have directional properties. Thus, such a method of communication might be useful for homing problems. For example, a ship might be able to find its way toward a signaling station on shore, and a swimmer might be able to find a ship on which a transmitter was mounted.

Although some signaling of this kind had been done by Samuel F. B. Morse about 100 years ago, practically no references to recent work along these lines was found in the literature. Accordingly, a number of models of transmitting and receiving equipment were constructed, tested, and then demonstrated to the Maritime Unit of OSS, the Navy, and groups informed of this development by the Office of Field Service, OSRD. These tests are described in a later section of this summary. During the course of this development, a sample of the British underwater craft called the Sleeping Beauty was obtained, and one model of the UWT was produced for installation in it.

It should be emphasized that the specifications were never precise and were modified from time to time during the development. Thus, a number of models of the UWT were built and tested, but the investigation of this method of communication must be considered incomplete because the investigation was discontinued in June 1945 before precise specifications were determined and before the investigation of possible designs was completed.

16.2 THEORETICAL BASIS OF THE UWT

The initial mathematical formulation [1] of the theory of the propagation of electric currents in water indicated the following important predictions, when two pairs of electrodes, one pair for transmission and one pair for reception, are placed in the same horizontal plane near the surface of sea water. The voltage pickup at the receiver is directly proportional to the current between transmitting electrodes. The receiver signal varies directly with the distance of separation of the two transmitting electrodes. The receiver signal varies directly with the distance of separation of the two receiving electrodes. The receiver signal voltage varies inversely as the cube of the distance between the transmitter and receiver. The receiver signal is maximum, if the transmitting electrodes determine a line which is parallel to the line determined by the receiving electrodes and if these two lines are perpendicular to the line between the transmitter and receiver. The receiver signal is theoretically zero if the receiving and transmitting electrodes are colinear. This theoretical formulation suggests the possibility of determining in advance just how much current is desired for a particular range. These theoretical data also show that the signals have directional properties which may be useful for homing. Also the inverse cube variation of receiver signals suggests that the system will be secure from enemy interference, even if he learns about the method and tries to detect the signals.

It is clear that the minimum practicable value of received signal voltage will depend upon electrical noise in the receiver, noise picked up from the water, and the bandwidth of the receiver. Early experiments showed that the noise picked up from the water was relatively low level unless it was caused by apparatus such as the ignition systems of internal combustion engines. Thus it was unnecessary to protect from noise, except when the equipment was to be used near such sources of noise as engines, motors with commutators, and so forth; in the latter cases, means were provided at the source of noise to minimize its effect on the UWT. The bandwidth must be about 300 cycles for code transmission and something about 3,000 cycles for speech. The receiver noise was calculable. Subject to experimental confirmation, which has been carried out, it was decided that there was a practical sensitivity limit of 10^{-8} volts for code and about 10^{-7} volts for voice. This specified the receiver sensitivity, that is, it determined the receiver signal that would be useful.

In order to determine the practical current that could be used in the transmitting apparatus, a theoretical investigation of electrodes in sea water was conducted. It was found that the resistance between electrodes was about 1 ohm and that it was essentially independent of the distance of separation. These effects had a strong influence on the practicable distance of separation of the transmitting electrodes because the cables which conduct the current to the electrodes must have low resistances and were, therefore, relatively heavy and bulky.

The theoretical computations concerning range, receiver sensitivity, and electrode resistance were confirmed by all of the experimental data using many different kinds of models. Thus, the theoretical basis of the UWT was found to be a dependable one.

16.3 EXPERIMENTAL MODELS OF THE UWT

Early models of the UWT are described very briefly in the following paragraphs. Following these brief descriptions there is a more detailed discussion of some of the later models, including the models which were installed in the Sleeping Beauty.

16.3.1 UWT Models C-101 and C-102

Model C-101 consisted of three 6SJ7 tubes which were resistance coupled and were tuned by a 1,500-cycle inverse-feedback network. For transmission, the tuned amplifier was adjusted to oscillate. Signals from the oscillator were fed into two hollow stainless-steel electrodes about two inches long inserted just below the surface of the water with a separation of about 100 ft. Signals were fed into this 5-ohm electrode system by means of a transformer chosen from standard items made by a manufacturer of transformers. The power supply consisted of a storage battery and a vibrator system which produced 400 v. The total weight was about 100 lb and the power output of the Model C-101 was approximately 7 w. This model was for boat installation. Model C-102 weighed only 8 lb. It used a 120-volt battery power supply, a circuit somewhat like the Model C-101, and produced about 0.2 w in a load resistance of 5 ohms. In tests conducted at Cape May, New Jersey, the vibrator power supply produced signals which interfered with reception on C-101, but signals from C-101 were heard at distances a little more than ½ mile by means of C-102.

16.3.2 UWT Models C-103 and C-104

C-103 was an improved model somewhat like C-102, and C-104 was an improvement over C-101. The power output of C-104 was 16 w. These two models with electrode spacings of 150 ft were operated successfully at distances up to 1.5 miles in tests at Cape May in 1944.

16.3.3 UWT Model C-201

This model was a first trial at the problem of designing something that might be used by a swimmer. It was a complete receiver weighing about 2 lb.

16.3.4 UWT Model C-206

This model was an unsuccessful attempt to develop a pulse-generator to send out damped pulses having a natural frequency of about 1,000 c, and a duration of a few cycles. The signal could be heard at 200 yd, but could not be heard at 400 yd and work on this approach to the problem was therefore discontinued.

16.3.5 UWT Model C-301

Model C-301 was a transmitter of 20 w output designed for minimum weight which was about 30 lb.

All of the models mentioned above were built to investigate experimentally the theoretical predictions

presented in Section 16.2 and to test the practicability of the idea of using the UWT for short-range communication. From these two points of view, the experiments were entirely successful although further models had to be designed for specific applications. They are described in Section 16.4.

16.4 LATER MODELS OF THE UWT

16.4.1 UWT Model C-105

This was a transceiver for code signals having a frequency of 2,500 c. Its range was 800 yd; its weight was 5 lb; and the life for continuous operation was 15 hr. The power output was approximately 0.1 w, the apparatus was waterproofed and tropicalized, and the standard R-30U earphone was used as the receiver. The complete outfit with the cables coiled on a reel is shown in Figure 1. At the left end of this

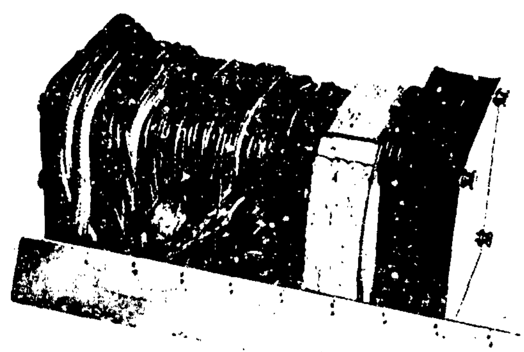

FIGURE 1. Model C-105 UWT.

picture some braided tubing can be seen. This was stretched over rubber tubing, and acted as the electrodes for the introduction of currents into the water. Each electrode was connected to the set by means of 60 ft of cable. Thus the maximum electrode separation was 120 ft, for which the range was 800 yd; for a separation of 60 ft, the range was 500 yd; for 30 ft, 310 yd; and for 10 ft, 140 yd. The control panel, as shown in Figure 2, consisted of a send-receive switch, a key, and an on-off switch and volume control. The wiring diagram of this apparatus is shown in Figure 3. Note that there are two 1S5 tubes and one 1S4 tube. The transformers which were used to couple the transmitter to the water and to couple the water to the receiver were specially designed and wound on hypersil cores. This device was designed specifically to be taken to the Pacific theater by a representative of the developing contractor who was assigned to the Office of Field Service to demonstrate this equipment and other devices.

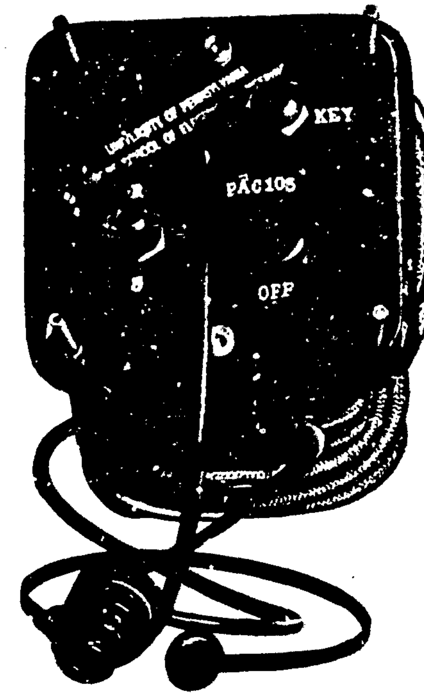

FIGURE 2. The control panel of Model C-105 UWT.

16.4.2 UWT Model C-500

After the first speech transceiver, Model C-400, was constructed, Model C-500 was built for the purpose of providing a practicable unit, which could be used underwater by a swimmer or diver equipped with breathing mask and microphone, and which could, if necessary, withstand pressures corresponding to depths as great as 80 ft. The apparatus was waterproofed by assembling the major items into heavy metal containers sealed by rubber gaskets. Two of these sets were designed for installation in the Sleeping Beauty. Two others were portable models to be used for tests on auxilliary surface craft and they were not waterproofed. The effective range for the reception and transmission of these devices was 250 yd when the electrodes were separated by a distance of 25 ft.

When the apparatus was installed in the Sleeping Beauty, one electrode was inserted near the bow and

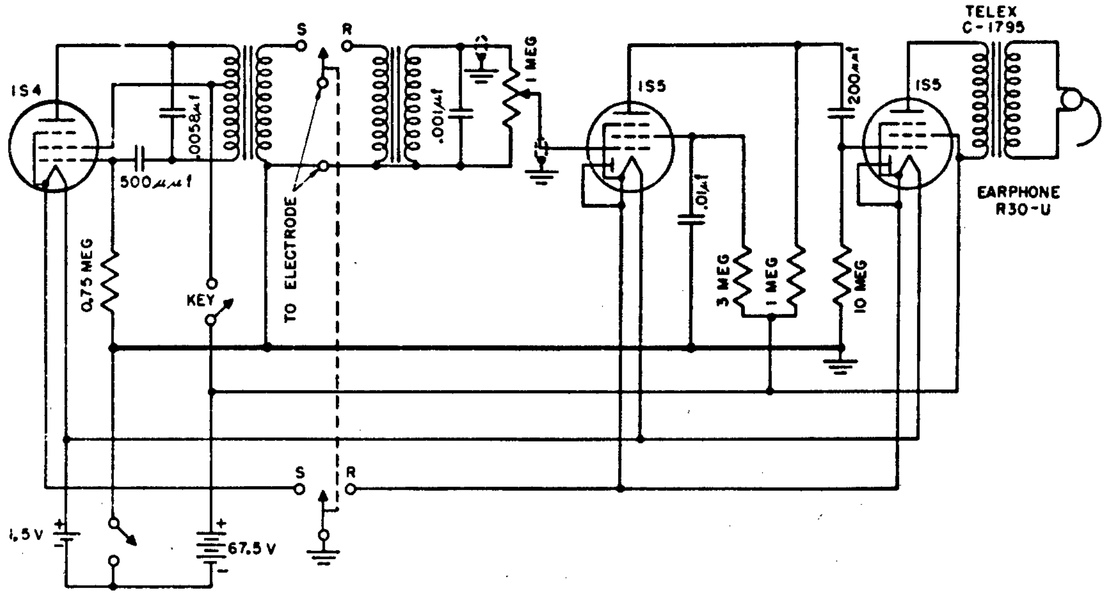

Figure 3. Circuit diagram of Model C-105 UWT.

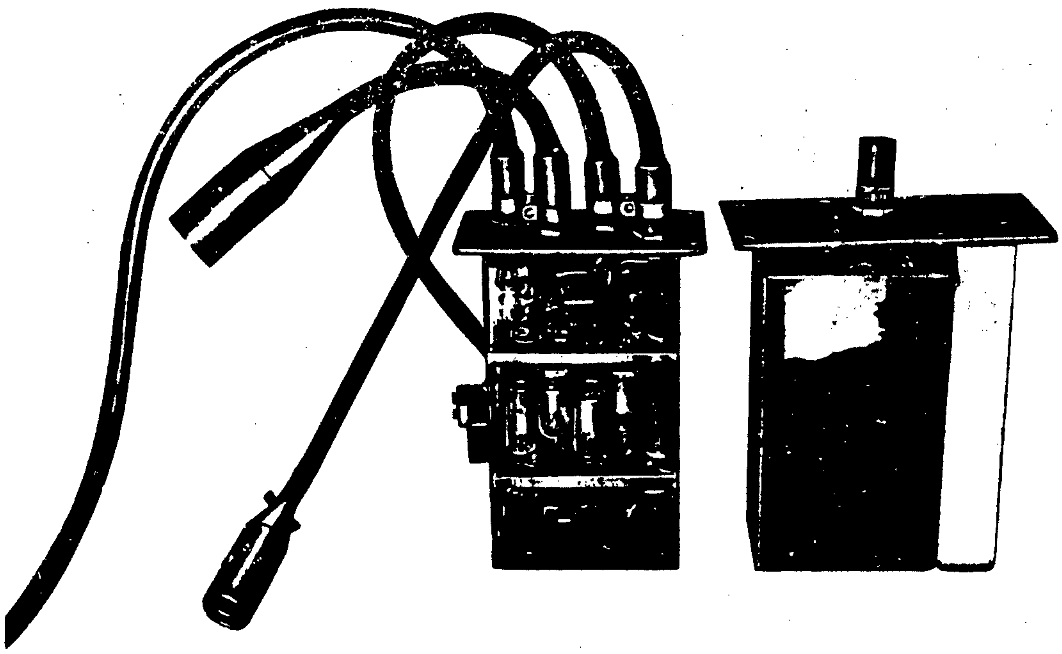

Figure 4. Model C-200 UWT: apparatus removed from case.

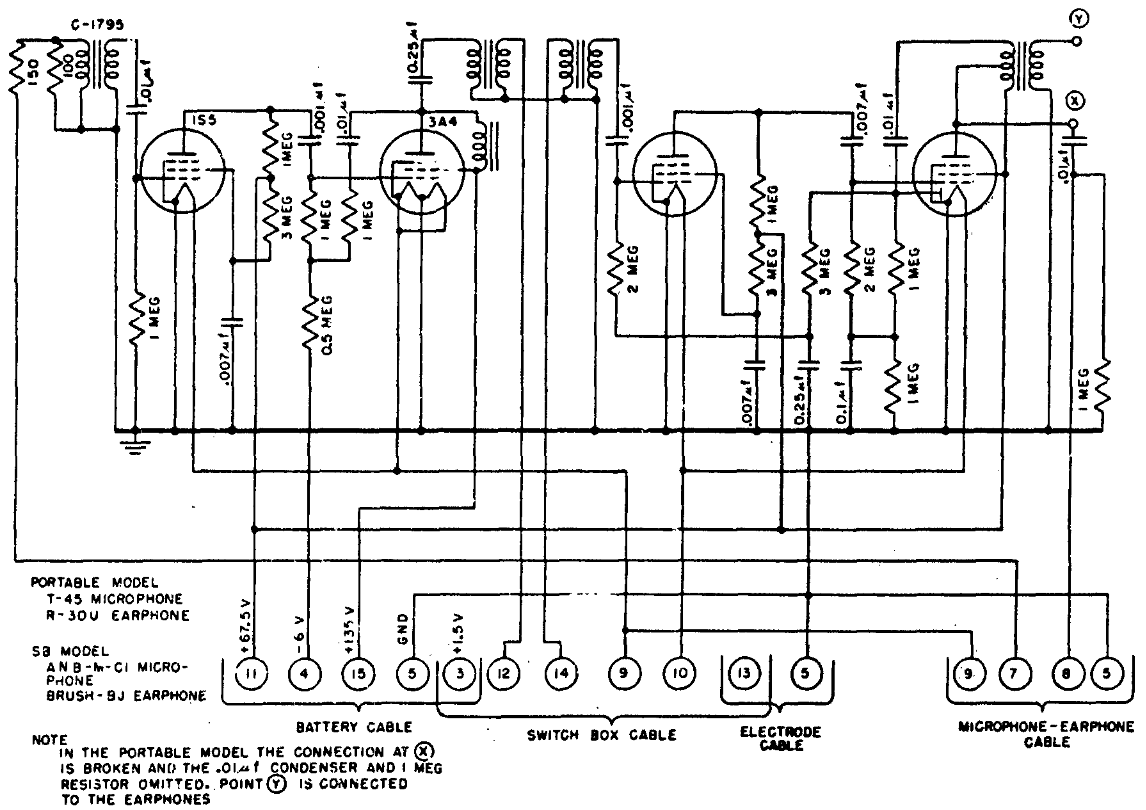

FIGURE 5. Circuit diagram of Model C-500 UWT.

the other electrode was held out from the stern by means of a flexible pole. The batteries and electronic equipment were installed within the craft. The electronic apparatus mounted within the submarine was enclosed in two cases, one for batteries, and the other for tubes and other components. These are shown in Figure 4. The circuit diagram of Model C-500 UWT is shown in Figure 5. The complete equipment, which was submersible, is shown in Figure 6. Note the waterproofed switch for changing from "transmit" to "receive" and the waterproofed earphone, both next to the mask.

16.5 TESTS OF THE UWT

Demonstrations of C-105 were carried out in the Pacific area (see Section 15.3) and, in addition to the tests at Cape May of the early models of the UWT, two test programs were undertaken at St. Petersburg, Florida, under the auspices of OSS, and the Navy.[2] At the latter site, two portable battery units, attached to the backs of swimmers equipped with diving suits, operated satisfactorily at a distance of 150 yd and a throat microphone was found to be preferable to a lip microphone. The waterproofed earphone was placed on the outside of the diving suit helmet, and performed satisfactorily. With the operators separated by 250 yd, one on each side of a small island about 50 by 400 yd, communication was satisfactory, although it is probable that no greater range could have been used.

One apparatus was installed in the Sleeping Beauty, one electrode being the propeller while the other electrode was a silver plated brass tube 1½ in. in diameter, 2½ ft long, trailing at a distance of 100 ft on an insulated cable. An identical set was installed aboard an Army rescue boat [ARB] with electrodes off the bow and stern having a total separation of about 75 ft. With the ARB stationary, the Sleeping Beauty was operated on the surface in a circle with the ARB in the center at a radius of about 150 yd. Null points were observed when the Sleeping Beauty and its electrodes were perpendicular to a line formed by the electrodes of the ARB. This is in accord with theoretical predictions. The range test was carried out with the Sleeping Beauty running on the

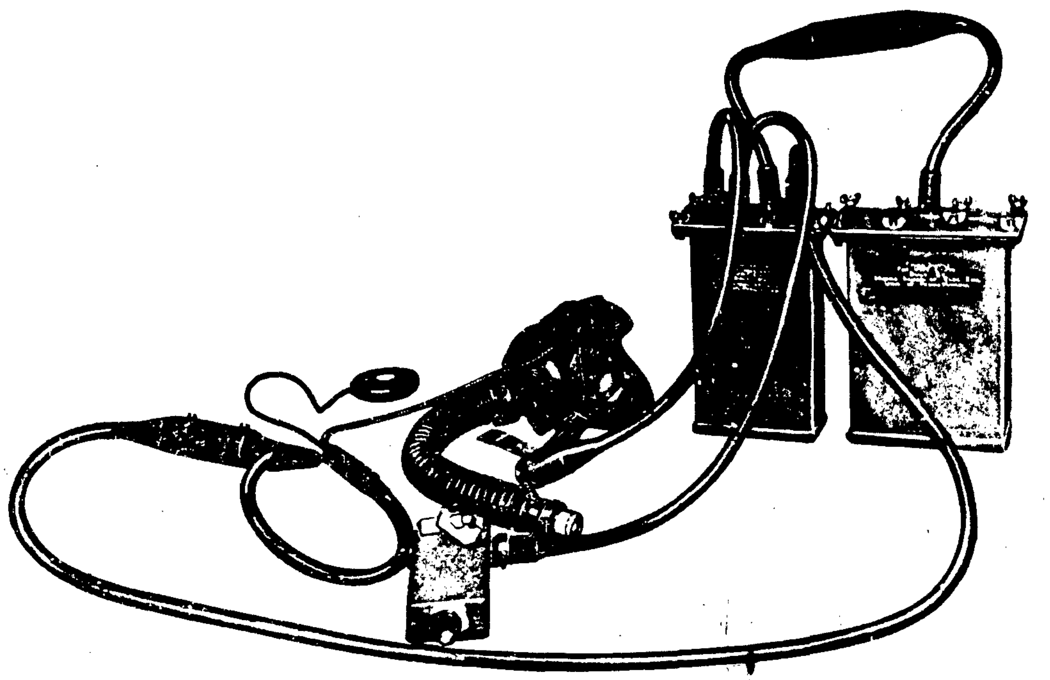

FIGURE 6. Complete equipment of Model C-500 UWT.

surface directly astern the ARB. Thus, the electrodes were all in the same line which is the condition for maximum range. The signals were still satisfactory at a distance of 600 yd, and it was not desired that this range be extended for security reasons. Reception at the surface was good only when the Sleeping Beauty was stopped or running at slow speeds, apparently owing to the acoustic noise of the splash of water at high speeds. When the craft was submerged at depths up to 14 ft, reception was good no matter what the speed. It was noted during these tests that interference was produced by the ignition system of a JR Navy craft when it was within 20 yd of the receiver and also that the receiver on the ARB became inoperable when the motor of a motion picture camera was less than 30 ft from the ARB. However the interference of the electric motor of the Sleeping Beauty was negligible throughout these tests.

Suggestions for modifications of the equipment based on these tests included the proposal that the transceiver and power supplies be placed in a single container, when used by a swimmer, and that the electrodes be in the form of cuffs, one on each wrist. Suggestions were also made to relocate the equipment used in the Sleeping Beauty to avoid interference with other facilities in the craft. Some of these modifications of the UWT were made, and subsequent tests were arranged as described below.[3] The chief purpose of these tests was to investigate the usefulness of the bow electrode fitted over the craft and the rear electrode consisting of 2 ft of tinned copper braid mounted on a rubber tube trailing about 10 ft astern. The switchbox with all the controls was mounted on the steering column of the Sleeping Beauty. The second UWT was set up in a flat-bottom wooden boat with electrodes about 33 ft apart; this spacing being approximately equal to the electrode spacing of the Sleeping Beauty installation described above. A range of about 200 yd was attained throughout the tests, and mechanically, the new electrode system appeared to be satisfactory. These tests also showed that a sensitive earphone was required for satisfactory communication up to 250 yd, but that the limit was about 200 yd using a bone conduction receiver. The demonstrations of the UWT in the Southwest Pacific area confirmed the range prediction, and, in general, the apparatus performed as expected. However, no specific uses for the UWT were suggested in that area, the observers desiring a longer range. They were quite concerned also about the necessity for a

shore operator's exposing himself along 100 ft of shoreline to place electrodes in the water.

16.6 CONCLUSION

It cannot be overemphasized that this development was carried out quickly near the end of the war without any precise designations of probable uses of the apparatus except for the Sleeping Beauty. The experimental results confirmed the theoretical predictions and it is to be assumed that further experimental investigations might lead to the production of more satisfactory transceivers of relatively sharply defined, and short, range.

Chapter 17

A COMPACT MICROWAVE TRANSMITTER AND RECEIVER AND MISCELLANEOUS COMMUNICATING DEVICES

17.1 INTRODUCTION (MWT)

It was the purpose of this development to construct and test a low-power microwave transmitter and receiver [1] for short-range, line-of-sight, two-way communication by voice or code, having a range of approximately one-half mile and usable as a relay. As developed, it could be set up on a tripod or could be held in the hand and used as a long-range megaphone. This microwave transmitter-receiver is abbreviated MWT in the following. In it, the 723 A/B klystron operated at approximately 9,400 megacycles as an oscillator and a crystal detector was used for reception.

17.2 TRANSMITTING AND RECEIVING CIRCUITS (MWT)

As the repeller voltage of the klystron was varied, different modes of oscillation were produced. Thus, for example, as the repeller voltage was changed from 90 v to 110 v, the power output increased to a maximum for a repeller voltage of about 99 v and then decreased again to zero. When the repeller voltage was adjusted approximately to the midpoint of one side of such a mode (in this case to about 106 v), the modulation could be applied to the circuit and a modulated 9,400-mc signal was thereby produced. This was essentially amplitude modulation, although there was a small percentage of change in frequency. For code transmission, the modulating signal was an audio-frequency oscillator.

The radiating system consisted of a rectangular horn. The receiving system comprised a half-wavelength antenna mounted in a parabolic reflector, and connected by means of a coaxial line to a crystal detector. Its output was fed to a two-stage audio-frequency amplifier having a gain of about 8,000.

In order to adjust the repeller voltage for operation at the correct point on a mode as described above, the monitor crystal was mounted in the horn and connected to a microammeter. The repeller voltage was adjusted until maximum reading was obtained on the microammeter and the voltage was then adjusted until the microammeter reading was one-half the peak value.

17.3 TWO MODELS OF THE MWT

Model F-101 receiver and Model F-201 transmitter were initially constructed to test code operation, but later the transmitter was modified to permit modulation by voice, and a second receiver was built for voice reception. The transmitter produced a beam of about 20 degrees, a power output of 10 mw, and a range of approximately ½ mile using the modified F-101 receiver. The weight of the equipment was 17 lb.

A subsequent model of the MWT, designated Model F3, was a transmitter and receiver arranged to be packed for ease in carrying and mounting. There were three carrying cases. One contained the control unit and was 11 x 7½ x 6½ in.; its weight was 10 lb; its power output was 10 mw. The second case weighed 34 lb and contained the batteries, the life of which was at least 15 operating hours. The third case contained the tripod and weighed 12 lb. Thus, the total weight was 56 lb. This device could be used as a transceiver for modulated code or for voice, and it could also be used as a relay station. The range for voice was about ½ mile, and as a relay station, the maximum safe range was ⅓ mile. The apparatus, mounted on a tripod, is shown in Figure 1. Note that the receiving parabola is mounted on top of the control box while the transmitting horn is within the control box. The microammeter on the face of the panel is for the adjustment of the repeller voltage as described above. Figure 2 shows the horn removed from one end of the case, and the modulator and receiver removed from the other end of the case. The circuit diagram of the Model F3 is shown in Figure 3.

17.4 TESTS OF THE MWT

As indicated above, relay operation over ⅓ mile, telephone communication over ½ mile, and a range for code of 1¼ miles were conservative ratings for the Model F3 of the MWT. This was shown by repeated tests in the vicinity of Philadelphia. However, at a field test conducted in July 1945 near Washington, D. C., a range of only 0.4 mile was achieved over an open field. It is believed that this slightly shorter range may have been caused by vegetation at a

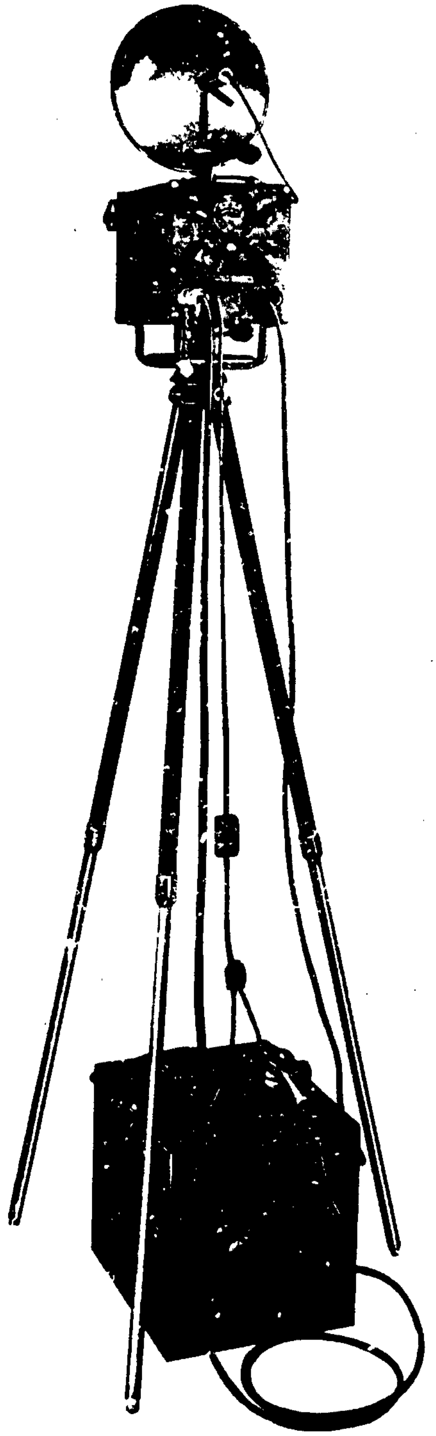

FIGURE 1. Rear view of MWT, mounted on tripod.

height of 1½ to 2 ft which decreased the effective height of each unit.

17.5 CONCLUSION (MWT)

The klystron used in this apparatus was not designed for battery operation and a tube designed for this specific purpose would be better. It is quite possible also that considerably higher frequencies could be effectively used for short-range devices of this kind and that the weight and volume of the equipment could be reduced by using RM cells and multiple horn units. The possibilities of the system were not fully explored.

17.6 MISCELLANEOUS COMMUNICATING DEVICES — INTRODUCTION

The following paragraphs comprise brief descriptions of several devices produced by the division's contractor in addition to the devices described in Chapters 15, 16, and the first part of Chapter 17 of this volume. The equipment described briefly below is discussed in more detail in a single volume[2] and represents either branch roads from the main line of attack on the problem of short-range communication, or measuring equipment required in the course of this investigation.

17.6.1 Short-Distance Signaling by Means of X Rays and Gamma Rays

A portable Geiger-Muller counter was constructed in order to determine its usefulness as a receiver of signals from radium and from X rays. The device consisted of a box 4½ x 5 x 1½ in. with a cylindrical extension 7⅜ in. long and 1½ in. in diameter; a battery, a vibrator, and vacuum tubes were mounted within the box, and a counter tube was mounted in the cylinder. The weight of the unit was 27 oz. Signals were heard in earphones connected to the device. The background counting rate was about 25 counts per min but this rate was caused to double (50 counts per min) by gamma rays from radium or X rays at the following ranges: for 0.6 mg of radium, the range was 30 ft; for dental X-ray apparatus operating at 60 kvp 5 ma, the range was 500 ft. Since the transmitting apparatus was expensive, dangerous, and, in the case of X rays, heavy, this method of short-range communication was not investigated further.

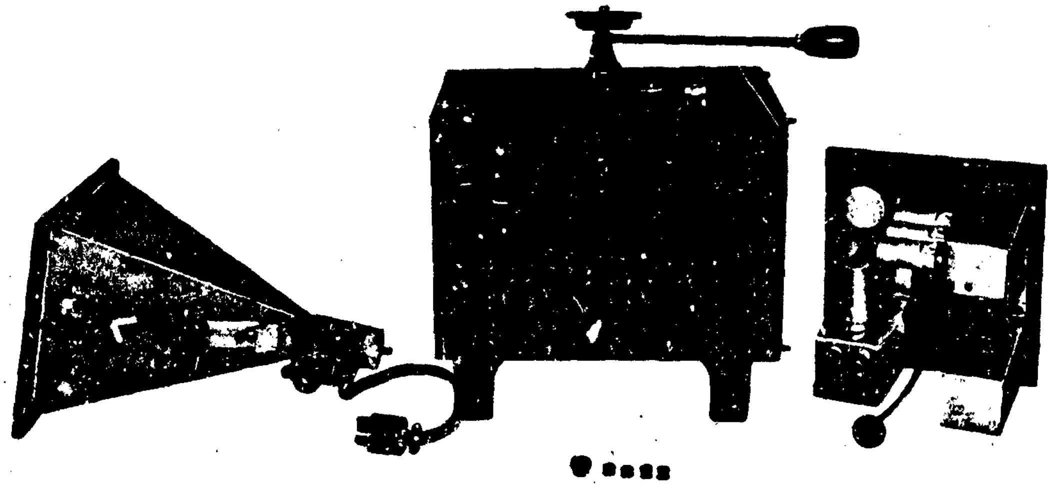

FIGURE 2. Partially disassembled view of MWT showing (*left*) the horn unit, (*center*) the case, and (*right*) the modulators (single tube) chassis, receiver (3-tube) chassis, and plug chassis.

17.6.2 An Ultrasonic Whistle and Other Acoustic Devices

An ultrasonic whistle of the Galton type was constructed of metal, and subsequent models were made of lucite. Fixed-frequency whistles from 15 kc per sec to 30 kc per sec were built. The power output varied from 50 to 100 mw, and the efficiencies were between 2½ and 5 per cent when blown by an operator with normal healthy lungs and chest. Signals from such whistles could be heard with a suitable microphone (see Section 17.9), a small receiver using microtubes, and an earphone. The receiving equipment would weigh about 2 lb.

A generator of audio frequencies called the hooter was investigated in conjunction with a study of canister locators (see Chapter 18). Figure 4 shows two models of the ultrasonic whistle and two models of the hooter. The hooters could not be blown effectively by mouth since they operated only at very high pressures. The hooter was also used as a source of underwater sound at frequencies of about 3,000 c and tests indicated that it might be possible to construct a device of this kind which would have a range of about one mile.

17.6.3 Condenser-Microphone for Ultrasonic Measurements

In order to investigate the acoustic and ultrasonic sources described, it was necessary to set up acoustic measuring devices. In the course of this work, a condenser-microphone was designed, constructed, and tested. The complete device with a mounting cylinder containing a pre-amplifier is shown in Figure 5.

17.6.4 Free-Field Room for H F Measurements

In order to carry out the tests described in the above paragraphs, and to calibrate the microphone described above, a small room was designed and built to have free-field characteristics at frequencies above 500 c. This room was 8½ x 9 x 11 ft and was lined throughout with blankets of glass wool folded into herringbone pattern (Figure 6). It was found that the inverse square law at frequencies above 2,000 c held for 9 ft along the diagonal of the room. Thus, for frequencies above 500 c, a quite small and inexpensive free-field room could be constructed.

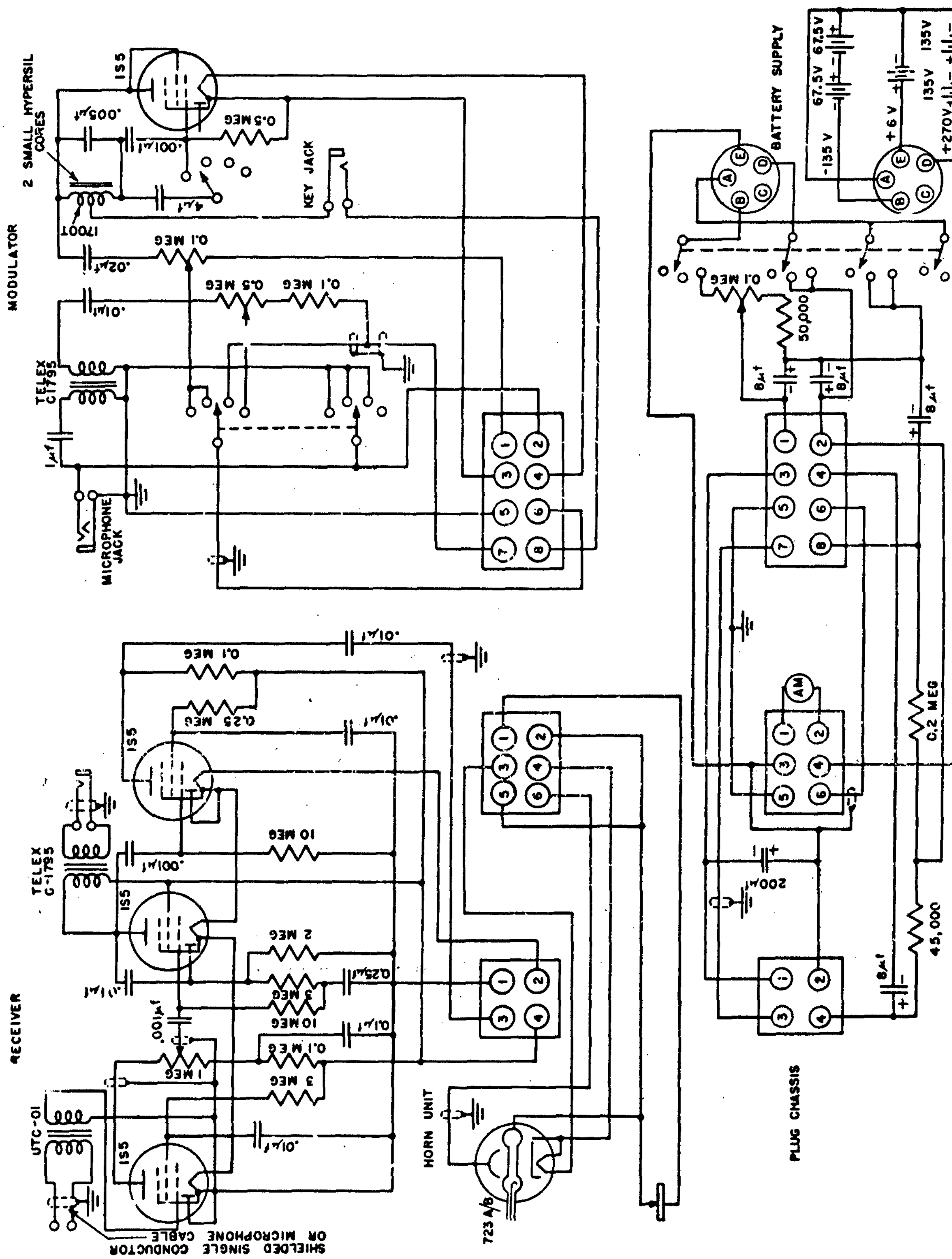

FIGURE 3. Circuit diagram of MWT Model F3.

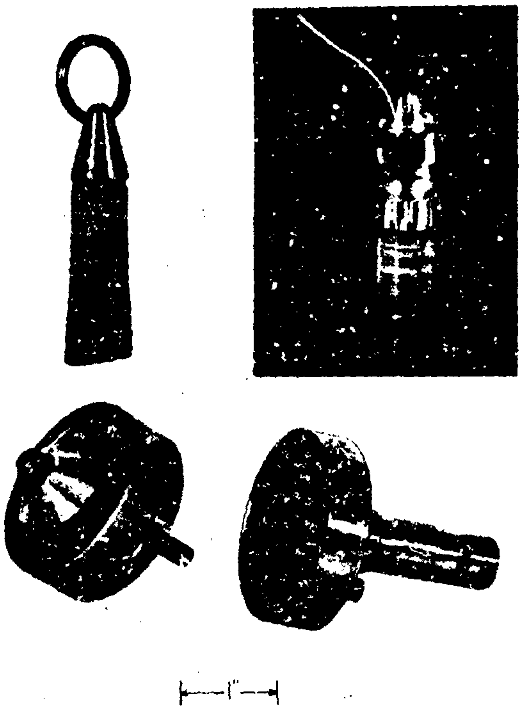

FIGURE 4. (*Top*) production models of ultrasonic whistle (*left*) brass, (*right*), lucite; (*bottom*) hooters (*left*) push-pull, (*right*) single-ended.

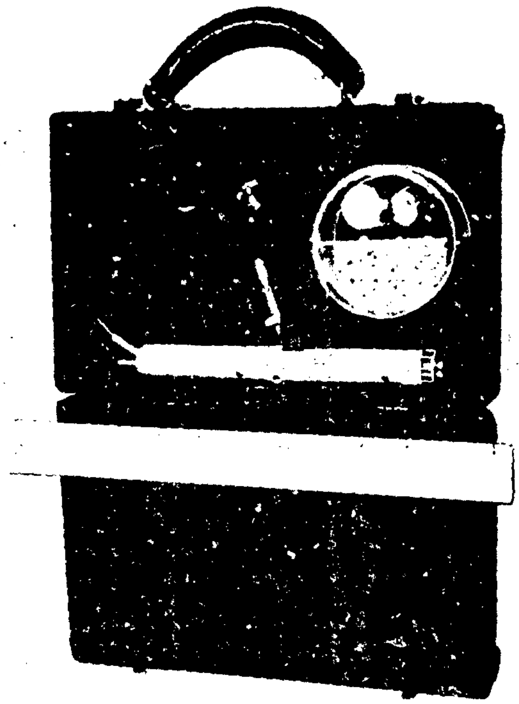

FIGURE 5. Condenser microphone with pre-amplifier mounted in carrying case.

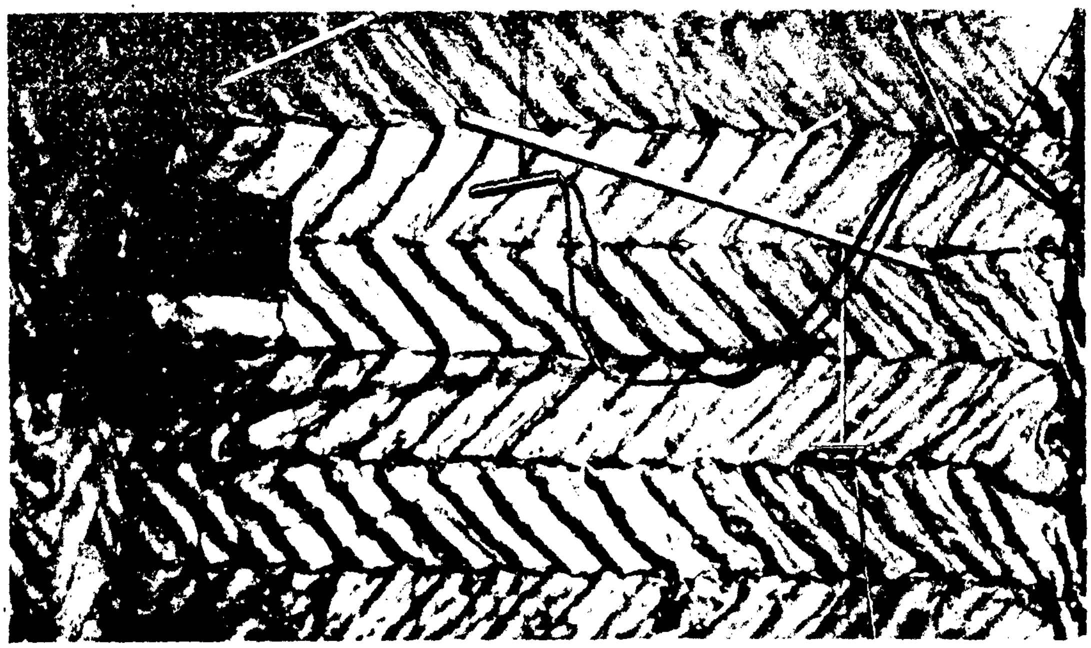

FIGURE 6. Interior view of field-free room showing construction of walls and arrangement of measuring equipment.

PART IV

FIELD ACCESSORIES

In this part of the Summary Technical Report of Division 19 is gathered together a miscellaneous group of devices which have been called field accessories because they would be of value to specialty groups operating on special missions but, would not by their absence, prejudice the success of such groups. It was the opinion of personnel in Division 19 that, by the use of the developed equipment described in the following chapters, operations would in a limited way have been made easier.

Probably the device described which would have the greatest usefulness to the largest number would be the military adhesive given in Chapter 19. By this development, a means was provided demolition crews for the rapid and secure affixing of explosive charges to targets, regardless of the surface conditions of those targets.

Of interest to the Airborne Command was the equipment described in Chapter 18 which would permit the more rapid and certain location of supplies dropped by air in difficult country. Chapter 21 should also interest airborne personnel, especially those embarking on individual missions designed to gather intelligence and elude detection.

In Chapter 23, dealing with the quieting of outboard motors, reference is made to work which successfully reduced the sound level of standardly issued motors by a percentage sufficient to allow the secret use of craft propelled by these motors close to enemy observation. For individuals, who might make landings by these means, a compact and reliable water purifier capable of one month's operation under the worst field conditions is described in Chapter 22.

Finally, in Chapter 20 are listed a number of simple but certain ways in which an Intelligence officer, operating clandestinely in enemy territory, could rapidly dispose of confidential documents which should not be allowed to fall into enemy hands.

The whole group of devices is therefore, somewhat tied together and is probably even more specialized than the developments described in other parts of the STR. The groups in the Services to whom these devices should be of interest would include the Corps of Engineers, the Airborne Command, the Army Ground Forces, Army Intelligence, and the Surgeon General's Office, as well as comparable Bureaus in the Navy.

Chapter 18

PARACHUTE LOCATING DEVICES

18.1 INTRODUCTION [2]

The supply of ground troops, by the dropping of stores from aircraft, became a familiar operation in World War II. During the tremendous movements in Western Europe, this dropping was on such a scale that it could be conducted en masse in the daytime with good percentage of recovery of supplies. Such was, however, not the case in isolated operations of a very small nature. Numerous field reports were read from time to time which showed that small parties on scouting or reconnaissance work became detached from their main source of supply and required support by aerial dropping of stores. Similar supply to aircraft forced down in unapproachable regions was a problem.

Since these operations generally were conducted close to enemy lines by small groups who would be vulnerable to attack, dropping was preferably done at night when enemy detection would be at a minimum. This posed the problem of supplying the reception group on the ground with simple means for the location of the parachute and its accompanying load. Darkness was a severe handicap but was not less serious than difficulties of terrain, vegetation, and the inevitable wide dispersal of containers which resulted even in the most careful supply operation. For example, under favorable circumstances a supplying aircraft dropping both metal containers and bundles at stalling speed (130 to 140 mph) at heights of about 400 ft produced a total spread among 18 containers of somewhere between 40 and 120 yd. If this good performance were even equaled under adverse field conditions, including darkness, thick jungle foliage, and rough terrain, it is easy to see that many invaluable containers would have been lost.

The problem was certainly an urgent one, but it was considerably complicated by the feeling among the potential users that no aid to location should be used which would alert the enemy. This would require that those on the ground be equipped with some manner of receiving or detecting apparatus unavailable to the enemy, and, in view of the fact that the groups to be supplied might not always be prepared for such supply, it seemed logical to division personnel that this requirement should be altered to allow use of the senses, but to place safety in a non-suspicious type of signal. This chapter describes a device based on this hypothesis and utilizing the sounds of a special whistle.

18.2 BASES FOR DESIGN [1]

Theoretically a great many physical phenomena could be used for a parachute locating device. Among the less likely would be odors, smoke, phosphorescent paint, fluorescent chemical reactions, and so forth. The more likely would include various methods of radio detection, supersonic signaling, infrared or visible light, and audible signaling. All of these were evaluated before a choice was made.

Radio was considered to have a number of important advantages, such as control of the frequency of transmission, security from the enemy, and independency of the type of terrain. However, it would be difficult to limit a radio transmitter to a short range, and the problem of designing a cheap, expendable, and robust apparatus seemed difficult. Presumably a spark generator would have been more sturdy than a vacuum tube oscillator, but the advantage of security would have been lost by the large spectrum emitted. Signaling by means of the electromagnetic induction field (IFT, see Chapter 15) has already been noted as a possible solution to the problem. Supersonic signaling would be ideal, if the receiving apparatus were not of great complexity. Unfortunately, attempts to utilize this system appeared unpromising especially because of the line of sight limitation.

Visible signals were already in use.[4] They were, however, visible at night at very great distances with loss of security and were, of course, very unsatisfactory in high grass, or underbrush.[5] Moreover, all the methods mentioned above required batteries, introducing the problem of functioning after exposure to the very low temperatures encountered in aircraft operation.

There remained radioactive emmanation, which was quickly shown to be impractical on economic and medical grounds, and audible signaling. The latter was chosen, since it required no additional receiving apparatus beyond the human ear. It could be simply produced without the use of batteries or complicated electric systems in a sturdy form capable of very rough handling and could be selected in frequency so

as to be rapidly attenuated beyond the desired distance of operation. The nature of the sound could also be selected to pass unnoticed, unless the hearer were listening carefully for the particular tone. This seemed to eliminate bells [5] from consideration, and the work of the division was therefore directed toward the development of a gas-blown whistle.

18.3 WHISTLE MODEL [1]

18.3.1 Choice of Frequency

From the point of view of security, the choice of pitch should be such that the attention of the enemy would not be greatly attracted. This indicated a frequency about 1,000 cycles, since this was likely to be masked by local noises such as those produced by mechanized equipment or jungle animals. On the other hand, the attenuation of sound in air increases by the inverse square law as the frequency is increased. This led to the belief that any frequency between 2,500 and 4,000 cycles would be satisfactory and to the ultimate choice of 3,000 c in a pure tone. It was felt that the latter would be easily detected by those who were listening for the sound, but likely to escape the attention of unsuspecting personnel.

18.3.2 Choice of Whistle

After the construction of several different models based on different principles already revealed in the published scientific literature, a very simple whistle was accepted as best for the purpose. This resembled the large steam-operated whistles used on boats. Air was ejected from an annular orifice toward a resonant cylinder placed a short distance away. The efficiency of this design was good, the tone emitted relatively free from harmonics, and the mechanical tolerances involved in mass production easily met.

18.3.3 Gas Supply

The above whistle required for good operation a supply of compressed gas at a pressure of about 25 lb per sq in. Simple connection of the whistle to a storage tank of gas at this pressure would have been suitable, except for the tremendous volume of gas which would have been required to give any reasonable operating life. It therefore appeared necessary to provide a two-stage gas supply with a reservoir of gas under very high pressure continually supplying a larger reservoir of gas maintained at the proper operating pressure.

Two designs were built and a number of prototype models. In one design (the so-called Kidde Model) the gas was stored in the high pressure tank at 1,800 lb per sq in. and by a valve system released to the lower tank, building up a pressure there of about 25 lb per sq in. In the second design (the so-called Mine Safety Appliance Model) the original high pressure cylinder had gas compressed at about 500 lb per sq in. and operated when the low pressure tank reached 15 lb per sq in. Schematic drawings of these two designs constitute Figure 1.

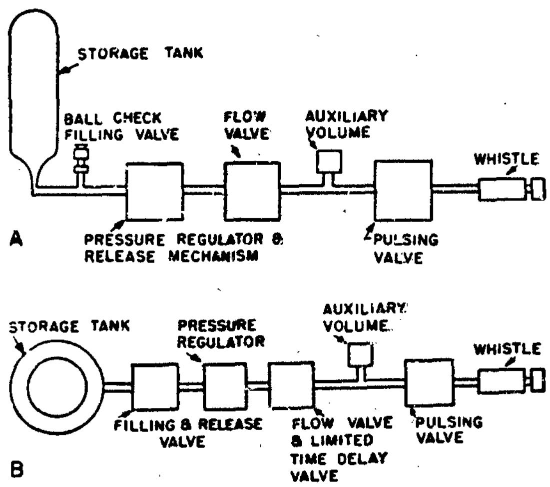

FIGURE 1. Schematic diagrams: Kidde and Mine Safety Appliance Models.

18.3.4 Intermittent Operation

Preliminary tests indicated that a listener could more accurately determine the direction of an operating whistle, if the operation were intermittent rather than continuous. It was found also that this type of sound was less likely to arouse suspicion. Moreover, an intermittent signal would require less energy for operation and, hence, give a longer time of service. Therefore the device was designed to give intermittent whistling with the average blast close to 2 sec in duration and the intervening silent periods between 4 and 10 sec.

18.3.5 Alternative Designs

Reference to Figure 1 indicates the schematic design for the Kidde Model, which was the device put into semi-production and later into somewhat larger production by OSS. Figure 2 is an external view of one of these models.

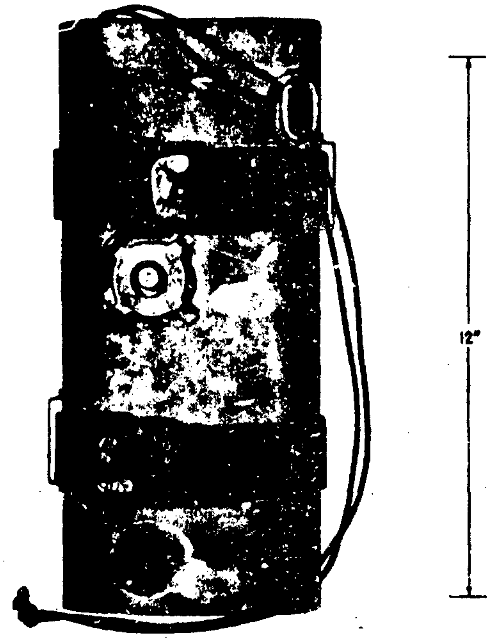

FIGURE 2. Canister locator — Kidde Model.

In this model gas stored in the pressure tank at 1,800 lb per sq in. was released when an external cord was pulled, opening a ball check valve. The released gas flowed into a regulated pressure chamber against a regulator diaphragm which was adjusted to maintain a pressure of approximately 50 lb per sq in. After leaving this step-down chamber, the gas flowed through a small leak into a 1-quart volume (the so-called low pressure chamber) and there built up the pressure to about 25 lb per sq in. For the first operation this required a period of about 20 sec, which was considered sufficient for the parachute and its load to have reached the ground. Thus operation of the whistle began only after the devices had landed, although it was initiated by the pulling of the external cord when the package left the plane. When the low pressure chamber reached the necessary value, a diaphragm valve opened and allowed the gas to flow into the whistle, which was attached to it by a short piece of rubber tubing. The gas flow into the whistle was more rapid than that into the chamber, and hence the pressure decreased to about 22 lb per sq in., when the valve reseated and the whistle was shut off. At this instant, the pressure began to build up again and the cycle repeated itself. Once located by a receiver, the device could be stopped immediately by removal of the rubber connecting line between the low pressure tank and the whistle.

The so-called Mine Safety Appliance Model [8] had an adjustable flow valve replacing the fixed leak into the low pressure chamber. In this way, the period between signals could be controlled. In addition, there was a delay valve which in combination was the diaphragm assembly allowed for an independently adjustable initiation time delay. This feature answered criticism from the Services that the initial 20-sec period was too brief. The remainder of the operation was essentially the same as described above.

Both devices were capable of being recharged from a cylinder of compressed gas but were considered by the designers to be expendable items which would have justified their cost by locating the unavailable loads they accompanied. It appeared likely that the second design would be somewhat cheaper in mass production because of less expensive valving. On the other hand, the second design illustrated in Figure 3 was of a less convenient shape because of the necessity of having the high pressure cylinder in the form of a doughnut. The Kidde Model measured $12\frac{1}{2} \times 5\frac{3}{4} \times 3\frac{1}{2}$ in. and weighed approximately 7 lb.

FIGURE 3. Canister locator — Mine Safety Appliance Model.

18.4 PERFORMANCE [3,4,5]

Only the Kidde Model was extensively tested, from which it appeared to be extremely robust and

reliable in its operation, being affected adversely only by very low temperature. This defect was a function of the valve seats, which when made of lead gave severe pressure losses during cold storage. The difficulty was nearly entirely corrected when these were replaced by rubber. Typical performance data are given in Table 1.[6] This performance was affected by

TABLE 1. Typical performance data on Kidde Model.

Chamber pressure	Initial delay period	Blast period	Silent period	Total functioning time
1600 psi	27 sec	1.9 sec	10.2 sec	28 min
1980 psi	31 sec	2.0 sec	9.7 sec	26 min
1850 psi	11 sec	2.7 sec	10.4 sec	28 min

exposure to high temperatures (120 F) to give a much shorter initiation delay period (4 sec) and an increased total functioning time (35 min).

The range at which detection of the locating device was assured was greatly affected by the terrain, the ambient noise level, and the wind direction. In a comparative test of this device with bell and light devices, it appeared to be largely a matter of personal preference which type seemed most secure. There was no doubt that the range of the whistling device was considerably greater, thus bell devices gave a range of 100 to 200 yd, lights gave an identical range, and whistles a range of 400 to 700 yd under the same conditions.[5] The above figures were obtained on a quiet day. On windy days, the effective range was often decreased to less than 300 yd, and it appeared as expected that this was further affected by the presence of external noises and by the type of terrain and vegetation. If the latter, in an individual operation, were not important because of fortunate circumstances, then undoubtedly lights would be more effective for locating devices, but, in general, where no control was possible over the choice of locale, lights seemed much inferior, since they were easily masked by accident. The manner in which a whistle locator would be used is shown in Figure 4.

When used in this way, the whistle in actual tests out-performed comparable light devices and failed to function only in the rare instances where the bundle lay over the locator, muzzling it.

In summation, it may be said that a choice between individual locators appeared to be entirely a subjective matter. To those in Division 19 connected with the work, the whistle device seemed preferable to either the bell device used by certain British groups or light device used by the Airborne Command. A really conclusive comparative test of the three was never undertaken. The value of some such locator was, however, apparent.

FIGURE 4. Carister locator attached to Airborne Command bundle.

Chapter 19

MILITARY ADHESIVES

19.1 INTRODUCTION

The standard demolition kits used by Army Ground Forces and Corps of Engineer squads contained equipment by which sappers could affix their charges to selected targets. The means employed were, in general, improvisations featuring particularly tape, wire, and wooden props, by which intimate contact between the charge and the target was hoped for but not always secured. The demolitions contemplated were performed on a great variety of surfaces such as steel, dressed or rough wood, machinery, and concrete, and the operations against these surfaces took place both during actual combat and behind the lines, so that the initiation of the explosive charges was frequently accomplished by either time delay Pencils (see Chapter 9) or by electrical blasting caps. For all such operations, there was a field requirement for an adhesive material, which, in the ideal case, could be smeared on the surface of the explosive charge and would affix that charge to the target for an indefinite period regardless of the condition of the target's surface. This meant the development of an adhesive retaining its properties over an extreme temperature range of 0 to 140 F and on all the above surfaces when dry, wet, oily, or dirty.

At the suggestion of OSS and the British liaison officers assigned to it, Division 19 was engaged in this development when liaison was established with the Corps of Engineers and later with the Army Ground Forces. The outcome of the cooperative effort was the development of two different materials, RD-43-141 and RD-44-41, differing slightly from each other in their behavior toward water but essentially meeting the above-described field requirements. Procurement of the former of these was undertaken by the Engineers in quantity. The product thereby obtained was superior to competing British developments and vastly superior to a similar composition issued by the German army.

19.2 THEORETICAL CONSIDERATIONS[1]

Following tests on 25 different types of commercially available adhesives, the division's contractor arrived at compositions made up essentially of three materials: a base, a filler, and a plasticizer. These three were properly compounded to meet the field requirements by a balance of their rheological properties: tack, yield value, and workability. Tack was defined as pull resistance and involved liquid flow or viscosity. Yield value was defined as the resistance which the composition offered to flow when subjected to a given stress. (This was generally applied in shear, rather than tension, because the former was a more difficult condition.) Workability was an estimate of the plasticity of the material and its handling properties under a variety of temperature conditions. Most of the commercial materials failed in their performance because these three properties were not properly balanced. The theory can be illustrated by Figure 1.

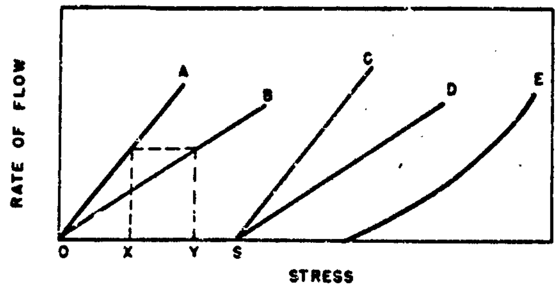

FIGURE 1. Theoretical behavior of adhesives under applied stress.

Curves A and B in the above diagram represent pure liquids, true solutions, or dilute suspensions, where the particles are loosely related to each other and there is no interlocking or overcrowding. Such materials, regardless of their tack, would not support any load in shear because an infinitesimally small load would start their flow. In other words, their yield value would be zero. The viscosity of material B, however, would be greater than that of material A, since a greater stress would be required to produce the same rate of flow (y vs x). Curves C and D represent materials which have a positive yield value. This is presumed to be because of an interlocking arrangement of the molecules or particles which must be overcome before the material will flow. Curves C and D would be true theoretical examples of this type. Both materials C and D have the same yield value but differ in other respects, C being less viscous than D and therefore having greater workability. D on the other hand, because of its greater viscosity, would resist sudden shock to a greater degree.

Based on these considerations, and particularly with the hope of retaining tack in the presence of

water, a number of mixtures containing rubber, rosin, vinyl, alkyd, phenolic, and urea resins were tested. Of these, only a mixture based on limed rosin or ester gum retained sufficiently its original tack when tested under water. This was shown to an enhanced degree when the gum was plasticized with Flexol Plasticizer 3GH. In the interests of workability, this mixture required the addition of a filler, and a study of the possibilities indicated a preference for asbestos. Thus on the basis of theory, a composition likely to meet the field requirement was discovered.

19.3 COMPOSITION RD-43-141 [1]

19.3.1 Choice of Plasticizer

Study of a number of plasticizers combined with rosin was made to determine the variations in viscosity with weight proportion, and the variations in viscosity with molecular weight. It was evident from this study that tack was primarily concerned with the viscosity range and was independent of the groups present in the plasticizer, the latter being important only in determining water solubility of the composition. In Figure 2 the performance of the best of these plasticizers with both ester gum (A) and rosin (B) is recorded.

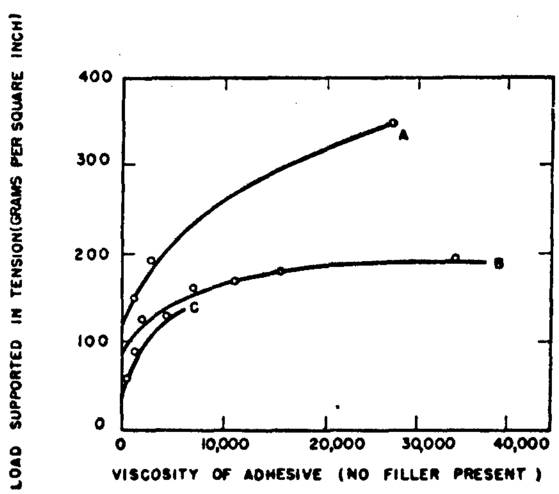

FIGURE 2. Viscosity-adhesion curves.

Curve *C* represents concentrations of phenolic resin giving a composition too stiff for application.

From Figure 2, it was apparent that ester gum was preferable to rosin with the best plasticizer found (triethylene glycol di-2-ethylbutyrate = 3GH). The latter plasticizer was, moreover, favorable because of its extremely low vapor pressure, even at temperatures as high as 200 F. The load-carrying capacity of mixtures of ester gum and 3GH appeared to increase with increase in viscosity. This, however, was limited practically by the increasing stiffness and was sensitive to percentage composition; thus variation of the amount of ester gum between 83 and 90 per cent caused a change in viscosity from 1,290 to 232,000 KV. At the same time, it was noted that viscous liquids without fillers would support no load for more than a few minutes without gradual yield, whereas the same mixtures mixed with fillers could support loads indefinitely.

19.3.2 Choice of Filler

Having shown the necessity for a third component in the mixture, a variety of fillers was studied, chief of them being carbon black and asbestos floats. The former in all compositions displayed an isothermal transformation upon agitation and rest, a phenomenon known as thixotropy, and thus, although such carbon-filled adhesive had excellent workability, the unpredictability of their behavior ruled them out of further consideration.

Asbestos floats, on the other hand, appeared well-suited and it remained only to determine the optimum amount to add to the ester gum plasticized mixture. Trials indicated that addition of 3 per cent of floats to 57 per cent of the mixture gave a composition having satisfactory workability and the maximum shear strength (180 grams psi). Alteration of this mixture by addition to the asbestos of wood flour, cotton linters, and so forth, produced no improvement.

Having come close to the final composition, the effects of variation in filler concentration and of variation in ester gum concentration were studied. Thus the final optimum composition was arrived at and was designated as RD-43-141. It was as follows: 30.4 parts of limed rosin (ester gum), 29.2 parts of 3GH plasticizer, and 40.4 parts of asbestos floats. This material was found to have good workability from 30 to 125 F and a yield value over this temperature range of between 200 and 90 psi on dry steel surfaces.

19.3.3 Choice of Base

As has already been said, early experiments indicated that ester gum was preferable to other mate-

rials. Having found what appeared to be the optimum composition of this material with plasticizer and filler, a search was made for other bases which, with these materials, might perform more satisfactorily. None was found, and accordingly RD-43-141 was recommended to the Services as the best material which could be developed.

19.4 COMPOSITION RD-44-41 [1]

Trials of the composition RD-43-141 gave good results on most surfaces except wet concrete.[3, 6] At Service request a further attempt was made to improve the adhesive mixture with regard to this point. This led to the incorporation of a fourth component, Bentonite, a silicate mineral having the property of swelling remarkably with water. It was believed that, if this material were part of the adhesive composition, its affinity for water and resultant swelling would cause the adhesive to penetrate into the rough concrete surface and provide a firm bond. Several compositions having added Bentonite were tested with gratifying results.

Eventually a mixture known as RD-44-41 was prepared in which the four components were apparently at the optimum concentrations as follows: 22.8 parts of limed rosin, 37.2 parts of 3GH, 21.0 parts of asbestos floats, and 30.0 parts of Bentonite. This mixture retained all the properties of RD-43-141 with regard to workability, tack, and yield value at temperatures between 40 and 125 F. A sacrifice had therefore been made in the low temperature range at which the material was suitable for use. On the other hand, excellent performance on wet targets, particularly with concrete, resulted. A choice between these properties was made by the Corps of Engineers, OSS, and the Army Ground Forces in favor of RD-43-141 and procurement of that was undertaken.

19.5 MANUFACTURE [1]

All the materials used were readily available and inexpensive. Specifications for them were given to the procuring Services, as well as tests which would assure a uniform and satisfactory product. The apparatus used for milling and kneading the adhesive was standard equipment, and the packaging of it in flat tin cans presented no difficulty. The chief requirement was that the adhesive strength under controlled conditions should be, at least, a minimum value and that the workability on the other hand should also be satisfactory. A balance had to be maintained between these two competing qualities.

19.6 PERFORMANCE

The development work required the use of standard test conditions, and these were selected as the load supported in shear by a given area of adhesive adhering to a standardized steel plate at a controlled temperature.[1, 4] Such laboratory procedures, of course, did not approach field conditions, and the work of the contractor was greatly facilitated by frequent and exhaustive trials of this kind performed by the potential users.[2, 3, 5, 6] In these trials, the standard demolition blocks used by the Engineers, the British, and the Army Ground Forces were applied with adhesive to a great variety of targets under winter and summer conditions, with and without oil, water, or dirt present.

A summation of these tests was sufficiently convincing to the Services to warrant adoption of the item. They may be qualitatively summarized as follows: against all types of dry, clean targets over the whole temperature range at which the adhesive compositions were workable, the application of ⅛ to ¼-in. adhesive to a standard block of explosive would hold that block in place on a vertical or inclined surface for an indefinite period (over 24 hours). Similar trials against the same surfaces thoroughly soaked with water gave less satisfactory results, but only in the case of wet concrete was the loss in efficiency serious, and this was rectified by the development of the composition RD-44-41. On the same surfaces coated with oil, results were comparable with those obtained on dry surfaces, inasmuch as the oil and the plasticized mixture were entirely compatible with each other. On the same surfaces heavily coated with dust or dirt, serious failure could be expected, but could hardly be laid to the adhesive for while this material was able to adhere adequately to the dirt surfaces, the latter had no strength of adhesion to the underlying target. This indicated that, in field usage, it would be necessary to prepare very dirty surfaces by a preliminary rub. This deficiency was not felt serious and could be easily overcome by adequate training.

In conclusion, it seems to the writer that, barring temperature range, a very satisfactory solution was produced to a very difficult problem, and it is believed that the use of these military adhesives would make the task of demolition crews considerably easier in the field.

Chapter 20

AIDS TO INTELLIGENCE

20.1 INTRODUCTION

Men on special missions either carrying or gathering Intelligence are in danger of interception, with consequent loss of vital information or revealment to the enemy of matters of interest to him. Persons engaged in such hazardous undertakings would therefore be greatly assisted by devices which would allow the complete, instantaneous, and certain destruction of documents in their possession.

Division 19 at the request of OSS evolved several developments, which should be of continuing interest to Intelligence operators. These ranged from a special type of paper, useful for individual sheet destruction, to fittings for briefcases and notebooks, where large quantities of ordinary paper could be very quickly destroyed by either incendiary or explosive means. The latter had particular usefulness in the destruction of large quantities of heavy paper, a problem which had always proved difficult, for paper in bulk is very slowly and imperfectly consumed by fire. In the sections below these various solutions are discussed individually.

20.2 DESTRUCTIBLE PAPER [1]

It was desired that a paper be developed and produced which would be suitable for the reception of all types of writing on both sides. This included pencil, pen, and typewriter. The paper should, in addition, be stable to prolonged exposure to adverse conditions of humidity and temperature and should be very rapidly destroyed by mastication or by maceration in water. This problem was therefore not met by the existing Chemical Warfare Service development of a nitrated paper, although the latter met the above requirements except in the method of disposition. The nitrated paper required combustion and was, of course, nearly instantaneous.

Two other papers had already been developed which bore on the problem. One of these utilized thin Japanese tissue paper called Yoshino Paper and the other consisted of thin sheets of cast sodium alginate. The first of these was unsuited because of its complete lack of wear resistance and its susceptibility to humidity. The latter paper was of better quality and was, in fact, used by British Intelligence officers. However, it also lacked good strength properties and, because of the extreme solubility of sodium alginate in water, was too sensitive to moisture to be satisfactory. The division's contractor chose to attempt the coating of Yoshino Paper with a composition which would increase the strength and resistance to abrasion when dry, and yet would not prevent the rapid disintegration of the paper base and the coating on maceration in water. Complete success attended this effort and a preferred coating composition was developed as follows:

Components	Pounds
Polyvinyl alcohol (RH–488)	75
Titanox WDL	90
Sorbitol lactate CRL 129 (78.5%)	64
Water	300
Alcohol (Shellacol)	300
Saccharin USP (insoluble)	0.25

Mixing of this composition in a colloid mill gave a mixture of the proper consistency on which the paper base was floated, then wiped lightly over a round doctor, and carried through a low-temperature drying oven. The procedure was practically identical with that used for making glue type mimeograph stencils. It gave a coating of 23.5 lb per ream or 78.4 per cent on the finished paper. Exhaustive tests of these sheets with all types of writing under conditions of 100 F and 90 per cent relative humidity with and without folding and pressing indicated most satisfactory performance. The individual sheets showed no tendency to stickiness, although they became somewhat limp. Under extremely cold conditions, no loss of flexibility was observed. It was determined also that the materials employed in the formula were not toxic when taken by mouth or allowed to be in contact with the skin. Sheets as large as $8\frac{1}{2} \times 6$ in. folded excessively into a small size could not be readily disposed of by chewing; however, smaller sheets were very quickly and easily masticated beyond the point of legibility.[2] A small production gave no difficulty.

20.3 PYROFILM [3]

20.3.1 Composition and Use

Prior to the entrance of Division 19 into this field, considerable work had been done by British research groups on the destruction of documents in despatch containers. For this purpose, the British had developed a potassium nitrate quilt used in conjunction

with a charge of thermit. Various size containers ranging from cigarette boxes to suitcases and cleverly booby trapped with elaborate switches had been devised.[4] None of them, however, performed with any great speed or efficiency, and an alert interceptor could very likely extinguish the flames before destruction of the documents was complete.

The division's contractor developed an entirely new incendiary material for this purpose. This was dubbed Pyrofilm and was composed of equal parts, by weight, of nitrocellulose plastic (celluloid) and finely divided sodium nitrate of technical grade. It was demonstrated that standard size batches of this mixture could be mixed by ordinary machinery to form a block of material which, after curing and drying, could be cut into sheets of any thickness between 30 and 60 mil. The time required to prepare a 250-lb block of the crude plastic was about two hours, and the curing time about ten days. It was susceptible to dyeing, like similar plastics. It was remarkably tough and showed little alteration on exposure to prolonged temperature and humidity cycles.

Investigation of mixtures employing chlorates, perchlorates, and dichromates indicated that none of them were as satisfactory as the nitrate. Some of their compositions burned more fiercely with more intense flame, but did not retain the good stability of Pyrofilm and were harder and more dangerous to mix. It was found that Pyrofilm could be readily ignited by the flame of a match and burned steadily, though feebly, in the open, liberating drops of molten sodium nitrate. Despite its ready inflammability, it had high shock resistance and was not detonated by blasting cap or severe mechanical impact. However, in contact with any organic material such as paper, the liberated sodium nitrate entered into reaction with a very intense fire and complete destruction of the organic material. Evidently the sodium nitrate combined with the carbon of the paper to form sodium carbonate and completely robbed it of its structure, leaving no distinguishable ash.

20.3.2 Initiation[3]

In the devices described below, this material was interleaved with the papers to be destroyed and was provided with what amounted to an instantaneous incendiary Pencil (see Chapter 11). This consisted of a tube containing a striker loaded against a compression spring directly above a Magnesium Matchhead. The striker, which was of split construction, was restrained by an inserted pin. Removal of this gave nearly instantaneous operation of the Magnesium Matchhead, which immediately fired the adjacent sheet of Pyrofilm and initiated the device. The various parts of this fuze and its operation are clear from Figure 1.

20.3.3 Incendiary Notebooks[6]

It was a simple matter to interleave pyrofilm sheets between the pages of a notebook and to equip that notebook with the instantaneous incendiary Pencil. Two sizes of notebooks were produced; they are illustrated in Figure 2.

In the assembled form the device was entirely safe, since the Pencil had a safety strip and required both a twist and a pull for operation. It was found by experiment that for complete and rapid destruction ten sheets of 16-lb paper should be enclosed by two sheets of 30-mil Pyrofilm of the same area. Since Pyrofilm was comparatively rigid, only a mechanical type of binding was practical for the notebooks, and the spiral type illustrated in Figure 2 was found to be very satisfactory.

20.3.4 Incendiary Briefcase

In those cases where larger quantities of loose paper required destruction, a unit package suitable for insertion in a briefcase was developed. This consisted of an accordion-type folder illustrated in Figure 3. It consisted of five sheets of 60-mil Pyrofilm, each surface coated with nitrocellulose by dipping in a lacquer, bound together to form an expanding compartmented envelope. Experience showed that such a unit weighing in all 2.67 lb would successfully destroy 68 sheets of ordinary paper of typewriter size weighing 0.61 lb. The confinement provided by the surrounding briefcase was most beneficial, and the time required for complete consumption of the contents was less than one minute, both in this case and in the case of the incendiary notebooks. Whether an alert interceptor could have arrested the combustion and recovered the papers was doubted because of the tendency of Pyrofilm to increase its combustion rate when smothered by sand or trampled on. Only the instant application of a large quantity of water would have arrested the destruction.

20.4 MESSENGER POUCH DESTROYER[5]

Prior to the successful development of the devices based on Pyrofilm, a joint NDRC-CWS development of a messenger pouch destroyer took place.

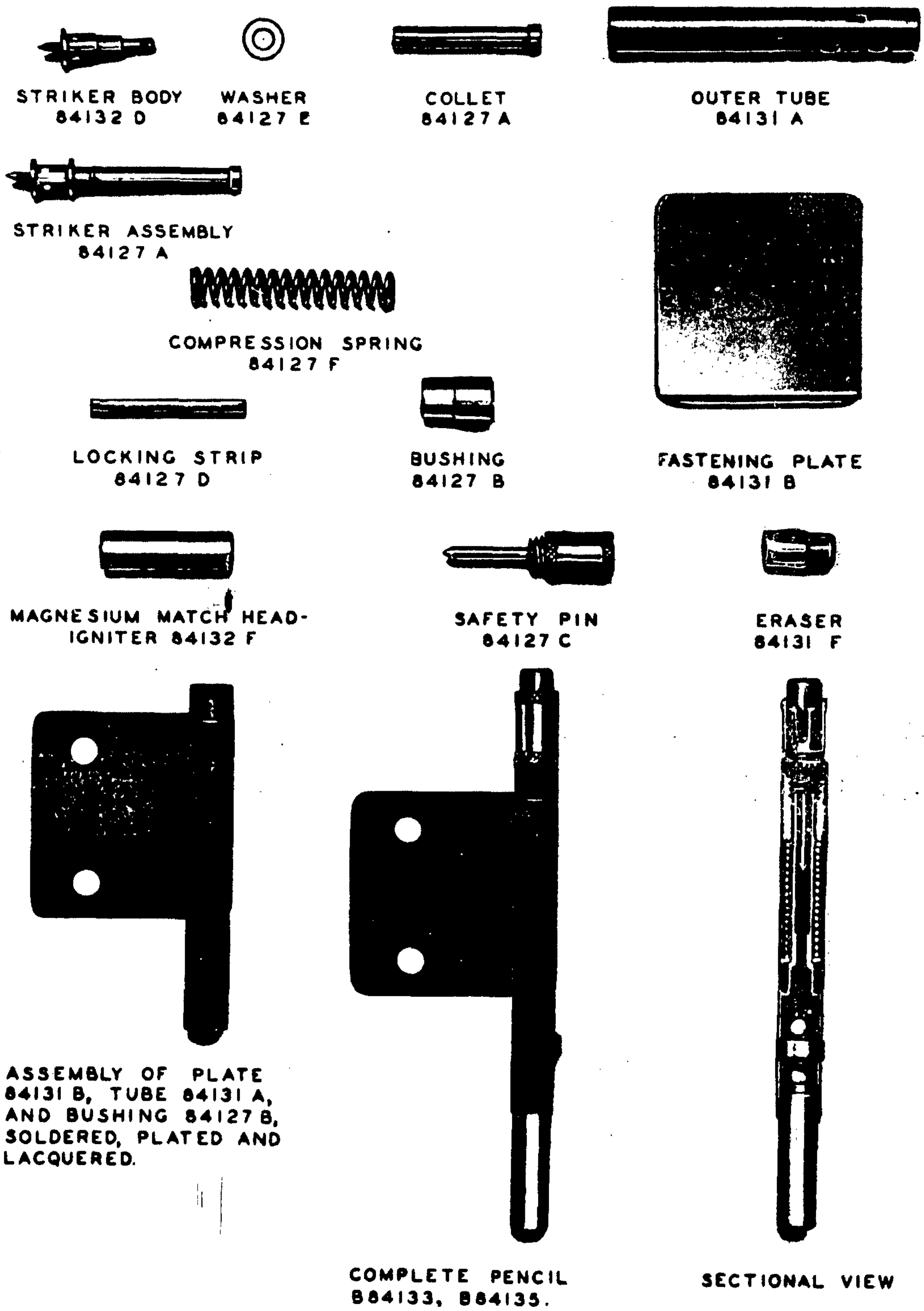

FIGURE 1. Instantaneous incendiary Pencil.

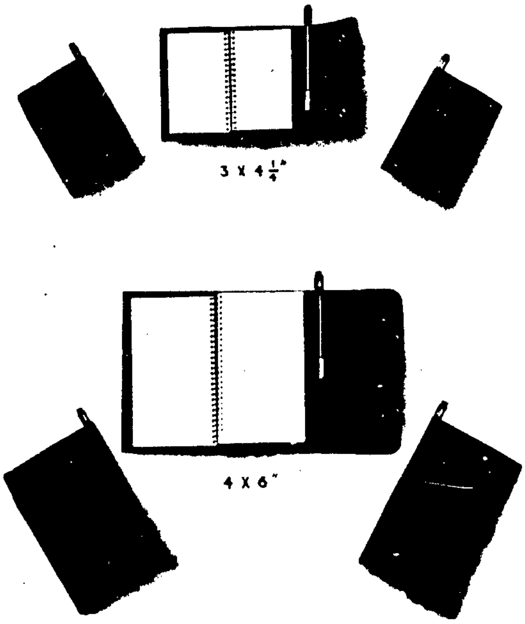

FIGURE 2. Pyrofilm notebooks.

This was known to OSS at the time when further work on the problem was requested, and it was felt by their officers that the Messenger Pouch Destroyer was too uncertain and slow in its action and too easily interfered with by an aggressive observer. Early designs of this unit were submitted by the contractor to the Chemical Warfare Service. Each of them was based on a celluloid case filled with an incendiary charge of two briquettes of fast-burning pyrotechnic (10 parts paraffin, 89 parts potassium perchlorate, and 1 part powdered charcoal). An explosive element was also provided with a delay train built into an insulated block cut to fit one side of the case.

Initiation was obtained by the use of a standard M-2 fuze lighter cemented to the outer side of the case. The unit was placed inside of the despatch pouch in contact with documents interleaved with nitrated paper and initiated by a pull on the fuze lighter. Following a delay of 5 sec the pyrotechnic burned briskly for about 45 sec and the conflagration of the pouch proceeded vigorously for another 2 min. As it began to die down, a violent explosion occurred scattering all traces of the charred documents.

This device would be useful for the booby trapping of unaccompanied pouches, where presumably the element of surprise would be so great that there would be no time for interference with the operation of the Destroyer.

20.5 EXPLOSIVE DOCUMENT CONTAINERS[7, 8]

In the central laboratory of the division the only other likely method of solving the problem, namely, one based on explosives, was undertaken. From this emerged three different containers, all of them based on the destruction of documents by the heat and blast of an explosive charge. The two smaller devices were made from small tins and were capable of carrying two sheets and 14 sheets of folded typing paper respectively.

Initiation was provided by an adaptation of the standard existing pull switches of either OSS or the Corps of Engineers. By the stab action of this switch, a time delay averaging 4.5 sec was ignited which in turn initiated the explosive charge contained in the bottom and top of each case. For the small case, this charge consisted of approximately 19 g of cast pentolite; for the larger case, it consisted of 75 g of cast pentolite. A user would presumably carry his secret

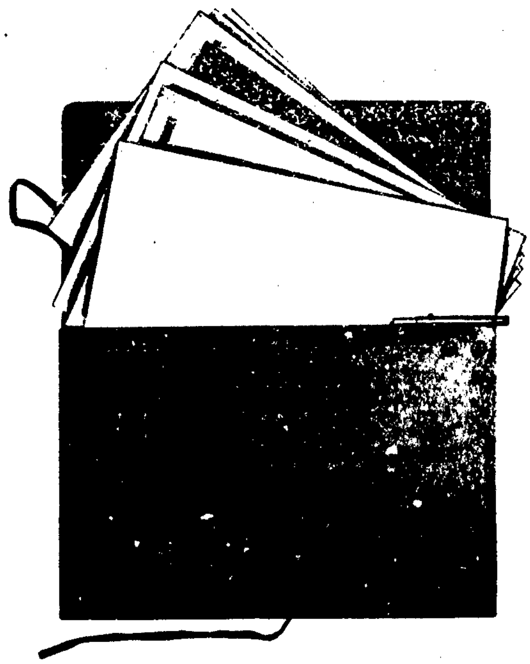

FIGURE 3. Pyrofilm envelope for brief case.

documents in one of these small pocket-size containers, and, when in danger of interception, would activate the delay unit and dispose of it at once. Its subsequent explosion could be counted upon to shred the contents beyond legibility.

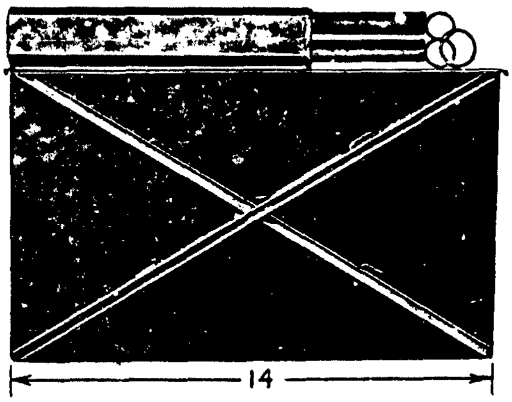

FIGURE 4. Explosive briefcase destroyer.

Neither of the smaller units was produced, since they were developed very late during the war; however, there was a limited production of a larger-size unit suitable for insertion in a briefcase. This is illustrated in Figure 4.

This unit consisted of a sheet metal container approximately 14 x 10 x ¼ in. loaded with 1.85 lb of 50/50 cyclotol (RDX-TNT), initiated by means of two Corps of Engineer 15-sec delay detonators which were ignited simultaneously by a single pull on a common ring. This unit had an overall weight of 3½ lb and was of a size convenient for insertion in the center compartment of a briefcase. The documents to be protected could be placed in the pockets on either side. Upon operation, it was found that 1½ lb of loose paper could thus be almost instantly destroyed, whether the briefcase was lying on the ground or was suspended in air. It appeared that the explosive blast shredded the paper and the heat of the explosion consumed it, so that no fragment large enough to contain a printed word was ever found. This unit was somewhat more hazardous to the user, but again was provided with a time delay so that he might dispose of it before its action. Presumably it would be absolutely certain in its destruction effect, since the chances of an enemy being able to interfere would be very small.

Chapter 21

DOG DECEPTION

21.1 INTRODUCTION

German Gestapo and Wehrmacht personnel employed carefully trained dogs to hunt down and locate suspected persons and to capture parachutists. The problem existed of how to thwart these dogs and their trainers in this pursuit, and considerable British work had been done along these lines prior to the entry of Division 19 into the problem at the request of OSS. Very little advance was made by the division over the British work, and this chapter is written largely to give greater publicity to the very valuable contributions made by our ally.

The problem had two aspects, namely, the use of the proper tactics and the use of specially designed devices (Dog Drags) to deceive the animal. No improvement was found over the British instructions in tactics; some improvement was found in the use of deceptive devices, and, if the problem were an active one, it was felt that a number of different chemical solutions could be used with advantage in the deception.

21.2 TACTICS [2]

21.2.1 Assisting Scents

After a dog has been given the scent of the man he is required to track, by smelling some article used or handled by the man or the room or ground where he has worked or slept, he begins to pick up the trail. In following the trail he is assisted by certain scents which may be listed as follows: (1) windborne scent traveling directly from the man to the dog, which may travel as much as a mile or more; (2) still air scent, which is left by the man in sheltered spots where there is little air circulation close to walls or under shrubs, or in similar locations; (3) track contact scent, which arises from the actual transfer of odor from the human skin or clothes to the ground or shrubs; (4) local track scent, which is caused by disturbance of the ground or crushing of the vegetation.

Obviously the harder and cleaner and more free the ground is from cover, as an open paved road, the more feeble the contact and local and still air track scents; hence, such spots or places much used by men or animals are unfavorable to the dog. Most favorable to him are locales covered with grass, sheltered by hedges where the ground is soft.

21.2.2 Preliminary Precautions

If possible, it is advisable that the person, who may be tracked, is wearing clean clothing and has had a hot bath. Obviously this is an unlikely requirement. He should remember that clean rubber shoes handled only with clean gloves will give good protection. He should avoid still air scents by leaping over obstacles with a stout pole, riding a bicycle, or even walking on stilts. To avoid windward scent, he should arrange his starting point to be on the windward side of his destination or at least make a large angle with the direction from which the wind is blowing.

21.2.3 Parachute Landing

The paratrooper should dispose of his visible equipment and parachute immediately on landing and prior to any attempt to lay a false trail. The more confusion he can create doing this, by walking through grass and bushes, is naturally beneficial. Several false trails may be laid at this time. These trails may be quite elaborate and run to a distance of as much as ½ mile. Use can be made of the above principles laid down for different types of ground and places favorable for scent may be deliberately chosen. The sequence of trails and their relative lengths would vary in a given operation.

21.2.4 False Trails

The essence of a false trail is that it apparently continues in a direction in which the man does not proceed, and, in this respect, it is important to remember that the dog, as well as the master, must be deceived. Another guiding principle is that the first part of the journey should not be in the direction of the final destination. The value of a number of false trails right at the start is apparent because the dog has little chance of selecting the proper one and valuable time is lost during which all trails become fainter. It is desirable that false trails should cross each other in an acute angle and that one or more of them should return to the original starting point. Before getting off a false trail, the man should clean his shoes of any unusual materials contacted while on that trail. The time spent in laying carefully conceived false trails would be well repaid in the delay caused the pursuers.

21.2.5 Clean Heel Trail

Having reached a spot unfavorable to the dog, and after laying many false trails, the man should attempt a fairly long trail (400 yd) which, without deception, would be counted upon to be hard to follow because of the nature of the ground and the direction of the scent. The use of a bicycle or a clean pair of shoes or clothing at this point would be very beneficial.

21.2.6 Drag Trail

Following the clean heel trail, the man should make use of deceptive devices known as the Dog Drag (see Section 21.3). This device dragged along the ground behind him deposits strong chemical odors on the ground and presumably these would suffice to further confuse or irritate the dog. The use of the Drag would be in conjunction with a number of false trails and would last so long as the scent appeared strong. Precautions in its use include assurance that none of the ampule contents has contaminated the person and that all the trail is on ground unfavorable for scent.

Having performed the above exercises and reached a spot extremely unfavorable for scent, the Drag is slung into a tree, a pond, or a bush, and the trail is ended.

21.3 DOG DRAG

This device is illustrated in Figure 1. It consisted of a brass cylinder containing a glass ampule of chemicals, and equipped at one end with a knurled screw and, at the other end, with a canvas sack. Tied to it was a length of rope. The brass parts of the device were identical with those used in the AC Delay (see Section 13.2). The operator was instructed to crush the ampule by turning the knurled screw, thus liberating the organic liquid contents into the canvas sack where the oily material was soaked up. In this operation, care was exercised that the person did not become contaminated himself. The Drag was then carefully placed on the ground and, by means of the rope, dragged behind the user until exhausted. As originally developed, the ampule contained equal parts of caproic, *i*-valeric acids and castor oil. This solution was not distasteful to the dog but was an extremely concentrated human footy odor. The theory behind its use was that the dog's nose would be so accustomed to this very powerful odor that when the Drag trail ended he would be incapabie of picking up the very faint footy odor of the final clean heel trail. If all the precautions given in Section 21.2 were followed, this was likely to be the case, but in numerous field trials[3, 4] success was variable, depending upon the dog and the skill of the Drag user.

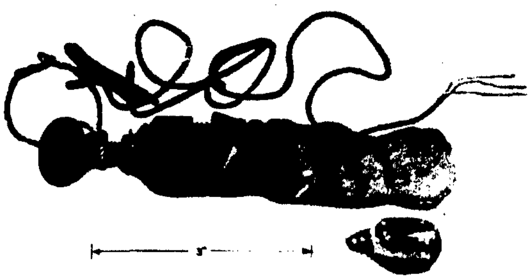

FIGURE 1. Dog Drag with ampule removed.

Attempts were made to improve the Drag by the substitution of other chemicals in the ampule solution. Among these were examples of chemicals calculated to paralyze the dog's sense of smell, to cause pain, to tire the dog, to arouse emotions, to distract the dog, and to repel him. None of the chemicals calculated to produce these effects turned out well. Of them all, only four would seem to warrant further consideration by future users. These were α-ionone, fresh grass juice, nicotine sulfate, and thioglycollic acid.[1] It was not demonstrated that any of these chemicals were superior to the original British composition and, in fact, the conclusion of the work was that the chemicals were secondary in their importance to the tactics. It was concluded also that, with the proper tactics and with or without the slight assistance of Dog Drag, a skillful man could elude the best trained dogs if his trail were more than ½ to 1 hour old before the hunt began.

Only one significant improvement was made in the British procedure. This was in the recommendation that clean paper bags[5] should be tied over the feet when a clean heel trail was begun. Thereby, of course, the contact odor was nearly eliminated.

Chapter 22

WATER PURIFIER

22.1 INTRODUCTION

Although a great deal of work on the problem of supplying the individual soldier in the field with sterile, attractive water had been done by such competent groups as the Surgeon General's Office, the Quartermaster, the Bureau of Medicine, and the Committee on Medical Research, Division 19 at the request of OSS made a survey of existing methods from the point of view of that group's requirements and did a certain amount of original work, which is the subject of this chapter.

The operational requirement stated to the division at first was later modified in the light of attainable performance. It was hoped, however, that a man on his own in the jungle country of Southeast Asia could supply himself for a period of one month with tasteless, sterile, colorless, odorless water, from the very unattractive streams of that region, and with the minimum quantity of accessory equipment. At the start, it was desired that this be accomplished without the use of chemicals such as the standard Halazone tablets issued in the Army (chloramine-T) or more modern substitutes such as C-DC (chlor-dechlor tablets, a product of the Wallace and Tiernan Company) or Bursoline (triglycine hydrotriiodide, a development of the Committee on Medical Research). This hope was abandoned in view of inability to insure sterility by filtration alone without chemical treatment.

A survey of existing portable mechanical filters disclosed three of promise which had been extensively tested by the services.[2] These were known as the Quinn Microfilter, the Wallace and Tiernan Portable Filtering Device, and the Bowser Piston Pump. The first and last of these depended upon ceramic materials for the main filtration and chlorination with Halazone for final sterilization. The Wallace and Tiernan unit was based on a renewable asbestos filter pad containing activated charcoal. It also depended on chlorination by the use of C-DC tablets which gave super-chlorination followed by chemical removal of the excess chlorine to give a potable solution. Using this device as a basis, the division's central laboratory investigated the use of a number of types of filter materials including ceramic plugs, porous silver metal disks, and beds of activated charcoal.

From Section 22.2 it will be seen that no basic improvement on the Wallace and Tiernan model was forthcoming, and this appeared to be the best of the three available designs. However, a redesign of the Wallace and Tiernan unit was made to produce a smaller, lighter device of more capacity, better suited for the use of an individual (Section 22.3).

The remaining work of the division was concerned with attempts to generate by means suitable for field use sufficient ozone to produce sterile, colorless, and odorless water directly. It was realized that the effectiveness of ozone for this work might be open to question. From purely chemical grounds, however, it appeared after investigation to be an unlikely method in any case. The results of that work are given in Section 22.4.

22.2 FILTRATION STUDIES

22.2.1 Ceramic Plugs[3]

Using suspensions of mud and Aquadag (colloidal carbon) in water, a great number of ceramic and porcelain filters were tested for rate of flow and effectiveness of filtration. Extremely variable results were obtained, even between examples of the same ceramic material. This indicated an uncontrollable variation in porosity and the danger of the development of minute cracks which were not easily located, but were easily formed because of the fragility of the materials.

It was found that the effectiveness of such plugs decreased very markedly with continued use, so that the rate of flow which, at the start, might be a reasonable figure under an attainable pressure of about 50 psi would drop in the course of a few minutes to a value of as little as $\frac{1}{1000}$ the original rate. Regeneration or cleaning of such filters was moreover very difficult, for backwashing under pressure did not usually fully restore the ceramic. Furthermore, if such plugs were allowed to dry with the adhering coat of mud, it became even more difficult to regenerate them.

It was thought that perhaps improved performance could be obtained by a pre-filter which would effectively remove the bulk of the insoluble suspensions. In this way, the ceramic filter would be saved for the removal of the last traces of very fine material. Pre-filters such as the Millbank Bag[4] were

somewhat effective but were felt to be too slow in their operation. More success was had with pre-filters consisting of beds of powdered metal and of charcoal. Grade B aluminum grain appeared to be the best of these materials, although it was difficult to make exact conclusions, since performance depended so largely on the turbidity of the water. It seemed possible that 40 qt of water containing 50 parts per million of fine mud could be clarified with a filter of this type having an area of 58 sq in. without backwashing, but merely by scrubbing the surface of the porous disks holding the aluminum powder. Gypsum, precipitated barium carbonate, and barium sulfate did not appear promising, although their trial was suggested by the thought that negatively charged viruses would be precipitated by positively charged adsorbents. It was expected that activated carbon would be used in any case to remove poisons, odors, and colors from the water by adsorption, but experiments with a variety of carbon preparations made it appear very doubtful that carbon would be any more effective in this regard than as a pre-filter of large particles. Pre-filters made of glass cloth, Nylon, and linen were all open to objections raised against the Millbank Bag and trials showed considerable tendency to clogging and very inefficient performance.

It was decided that ceramic plugs, with or without pre-filters, held no promise for the construction of rugged portable units of reasonably long life.

22.2.2 Metal Plugs [3,5]

It was proposed to circumvent some of the difficulties encountered with ceramic plugs by the use of metal plugs formed by powdered metallurgy. It seemed possible that the porosity could be better controlled and, very likely, that these plugs would be completely resistant to breakage. Moreover, it was hoped that, if they were made of metals such as silver, a certain bactericidal action due to the metal surface would perhaps give sterile water by filtration alone.

Using a series of silver disks of known porosity, studies were made with clay suspensions. It was found that resistance offered by the accumulating filter cake of deposited clay was practically the same for all disks regardless of pore size. This led to the assumption that finely porous metal disks behaved in the optimum manner; that is, they were fine enough to hold the clay particles and were uniformly porous enough to spread the resulting filter cake evenly on the surface, giving the minimum thinness and maximum rate of flow. Tests with regenerating such filters by back pressure and scrubbing under running water showed that the disks could be restored to about ¼ their original efficiency without trouble. However, when organic material was added to the suspension of clay, the flow rate could not be maintained by this means and it required heating of the disk nearly to red heat to restore the disk to its original usefulness. Silver disks used in conjunction with pre-filters gave somewhat better performance.

At this stage attention was paid to the sterility of the water passing through such disks to determine whether the disks were bactericidal. The results were variable and not related to pore size. Some disks provided sterility in some trials and not in others, and the only effectiveness of the silver appeared to be in preventing growth of bacteria through the filter, which was an additional handicap of the ceramic type.

It was concluded that porous silver filters, while seeming to have points superior to ceramic materials, were not satisfactory because of the tendency to clog, with or without pre-filters, because of the variable performance against organisms, because of the probable excessive weight of the powerful pump required for an effective unit, and because of the mechanical complexity of designing an individual light, portable filter based on them.

22.2.3 Filter Pads [5]

Among the pre-filters tried, had been the type used by the Wallace and Tiernan Company for their portable unit and known as Seitz K5 Pad. Further trials of this showed that it had high retentiveness and good resistance to clogging, while retaining a rapid flow rate. Interestingly enough, it also showed fair ability to give sterile filtrates, although it was not entirely reliable. It appeared that this would be the best filter on which to base a portable unit, provided a redesign of the pump could be made in the interest of lower weight and lower unit output.

22.3 MECHANICAL DESIGN [2]

Using the general features of the Wallace and Tiernan device and depending upon the Seitz K5 Pad for filtration, a small pump and filter unit was constructed as shown in Figure 1. The device consisted of a diaphragm, pump, and a filtrate collector and a filter supporting vessel, which were drawn tightly together by a ring clamp screw to confine the filter disk on a perforated metal disk. A number of the

parts were the same as those used in the Wallace and Tiernan Device.

The intake and exhaust valves were both located in the main pump body. The intake valve assembly was made of Monel metal, and the valve was fastened with a rubber washer cemented to the metal and held by a screw. The exhaust valve led through the middle of the pump body and into the filter chamber. The main pump body, the diaphragm plates, the clamp ring, the filtrate receiving vessel, and the perforated plate were all of aluminum. The device weighed 13 oz, had a maximum diameter of 3.84 in. and a height of 2.19 in., a size convenient for pocket carrying. The intake tube was 5 ft of $^5/_{16}$-in. rubber tubing, the two ends of which were attached to the tubulature of the pump and to an intake strainer and float, which served to remove gross contamination and to protect the valve and pad by pre-filtration. This strainer consisted of a sock of olive drab Nylon cloth on a spring frame. It floated about 1 to 6 in. below the surface by attachment to a cylindrical cork float. The water drawn by the pump therefore came from close to the surface, where it was relatively free of suspended matter.

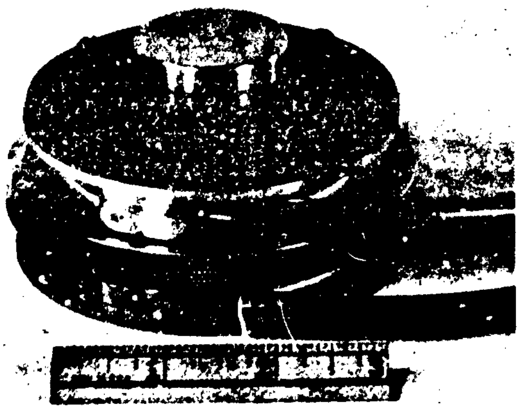

FIGURE 1. Small filter-type water purifier.

The pump had a capacity of 2 cu in. per stroke and required 30 strokes per qt of water. It was self-priming and foot-operated. The pressure developed depended upon the operator's weight and in lb per sq in. was roughly ¼ his weight in lb. Using a clean filter pad with clear water, the optimum pumping rate was 1 qt per min. The effort required was not tiring. The filter pads were circular, 3⅝ in. in diameter. Its performance on moderately turbid semi-stagnant pond water is given below.

TABLE 1. Time required for delivery.

Quantity	Time
First quart	1.08 min
Second quart	1.5 min
Third quart	2.08 min
Fourth quart	3.5 min
Fifth quart	5.1 min

Seventy-two pads weighed 1 lb, and, while the raw water to be filtered and daily requirements would vary considerably, one pad per day was estimated to be sufficient for use, hence, one of these pumps with 1 lb of pads and the necessary chemicals for water sterilization would provide filtered water for at least 60 days at a total weight of not over 2 lb. The chemicals recommended could be any of those ordinarily used. It seemed to the workers in the division that if Bursoline were standardized by the Surgeon General's Office this would be the best choice. Failing that, the C-DC tablets of the Wallace and Tiernan Company appeared most suitable for quick sterilization.

22.4 OZONE STUDIES [6]

22.4.1 Evaluation of Ozone

Previous work [1] indicated that ozone might have value as a chemical capable of producing sterile water in very brief periods of time and in very small amounts (10 mg in 1 liter of water). It was hoped that a simple way of generating ozone in the field could be discovered for the individual soldier's canteen use. This treatment would presumably, not only yield sterile water, but would remove the color and odor associated with river water. Excess ozone would not be harmful to the individual in contrast to chlorine. It was realized that the true effectiveness of ozone against all types of organisms and viruses was not known. Fortunately, or unfortunately, the necessity of investigating this point never arose, since no practical method of generating ozone in the field by portable equipment could be found.

22.4.2 Preparation by Oxidation of Phosphorus

A survey of the chemical literature indicated that a good yield of ozone might be obtained by the oxidation of white phosphorus in a rapid stream of moist air in the dark. With the rate of flow varying from a few milliliters to several liters per minute, the amount

of ozone obtained was found by test to be about 1 mg per hr. This rate of production was obviously too low to make the method practical.

22.1.3 Electric Discharge

The chief industrial source of ozone for water sterilization is silent electric charge. Voluminous literature on the subject exists. Conceivably a small hand-operated electro-mechanical device could be designed which might produce ozone directly from the air by means of this principle. The possibility was not investigated.

22.1.4 Preparation of Persulfates

The persulfates as a class in acid solutions liberate ozone. It was hoped to find the optimum conditions for this reaction and perhaps to prepare tablets which would spontaneously react to give a quantity of ozone sufficient to sterilize a single canteen. Tests definitely confirmed the generation of ozone by this chemical reaction, at temperatures, however, which were not attainable conveniently in the field (70 C). It was felt that the mechanical difficulties of devising an apparatus suitable for use with the reaction were insurmountable. Unfortunately, the yield of ozone was 5 per cent, the yield of oxygen 95 per cent, from the reaction. If a catalyst could have been found which would have reversed these figures, the chemical method would have been a possibility.

22.1.5 Preparation by Electrolysis

It was found that a portable generator operated by hand, motor, or storage battery could provide sufficient ozone to be useful. However, this meant considerable equipment, with increase in weight and loss of smallness and compactness; hence, although experimentally feasible, the method was not felt to lend itself well to actual field use. It was calculated that a 6-v storage battery by electrolysis of a 1.2 specific gravity sulfuric acid solution using a lead jar for the cathode and a 1-centimeter lead disk for the anode and having a total volume of 1 liter would provide 1 liter of sterile water every 5 min. The device would be susceptible to traces of impurities and would obviously not answer the original field requirement. It might warrant further study for use at a fixed camp, but only if ozone were to be evaluated as a sterilizing agent.

Chapter 23

QUIETING OF OUTBOARD MOTORS

23.1 INTRODUCTION

A desire was expressed to Division 19 by OSS and British liaison officers [3] assigned to it for development work on the silencing of outboard motors which were already in use in the field for reconnaissance work. These motors were employed with small craft, for the purpose of effecting landings on enemy-held coasts by men assigned to gather information and later were required for their escape. It was important that the coast be approached with a minimum of noise and that the escape attract no attention.

The motors already used were four in number: the Johnson POLR 22 hp, the Johnson K 9.8 hp, the Evinrude Lightfour 9.7 hp, and the Keikhaefer Mercury Rocket 6 hp. The problem was essentially the development of silencing kits which could be shipped to the field and installed on motors already issued. It was not the problem of devising a silent outboard motor. The work resulted in considerable improvement in the performance of all the above with the exception of the Johnson K.

Much later in the program, Navy groups in California at the San Diego Navy Yards asked for and received support in the silencing of 50-hp Evinrude motors used by the Navy with 32-ft Chemold Plastic surf boats. The principles discovered in the original work were successfully applied in this new problem.

The program was handled for Division 19 by the Engineering and Transition Office of OSRD, and, through that office, the support of Section 17.3 and the Electro-Acoustic Laboratory at Harvard University, as well as a group at the University of California at Los Angeles, were secured. Without the active cooperation of the Engineering and Transition Office and these assisting laboratories, the program could not have been successful.

23.2 METHODS OF APPROACH

Two entirely different methods of solving the problem presented themselves and were used by the different groups. The contractors in the east preferred to analyze the sources of sound and to silence them individually.[1, 2] The contractor in the west preferred to silence the motor by any conceivable means [4, 6] and then to back off from the ultimate obtainable performance to the performance which could be secured by methods usable in the field. Both of these methods eventually came to the same conclusion.

An arbitrary decision was made to eliminate from consideration noise caused by the boat. This included the boat's acting as a sounding board for transmitting the motor vibrations to the atmosphere and also the considerable noise due to the passage of the boat through water and against waves. No attempts were made to develop a boat of the best design for silence.

The early tests were conducted in a Jury Rig and sound measurements were taken in a number of different positions by an ERPI Sound Frequency Analyzer. Analysis of the noise spectrum was made from 10 to 10,000 cycles. Absolute noise levels were determined. The unsilenced engines were thus found to behave as shown in Figure 1.

Tests were also made in which the various motors on actual boats, when going directly away from a beach, were evaluated by a listening jury. Table 1 gives the performance of the unsilenced motors under these conditions and the peak engine rotation frequencies. All these distances were measured at full throttle. The serious need for sound reduction is very apparent from this table.

TABLE 1. Performance of unsilenced motors traveling from beach

Motor	High peaks	Maximum distance heard
POLR	86 (333 cps)	2,930 ft
Mercury	79 (267, 533, 667 cps)	2,400 ft
K	73 (400 cps)	1,800 ft
Lightfour	74 (400 cps)	1,300 ft

23.3 NOISE SOURCES [1, 2]

23.3.1 Exhaust

This was the most obvious source of noise. In most of the motors, it was taken care of by underwater exhaust. In the 22-hp Johnson POLR, this was the case and the demonstrable reduction in noise level at all harmonics averaged roughly 10 db. Comparable results were not obtained with the Johnson K. In this case the underwater exhaust created a burble which appeared to be due to the breaking of the exhaust bubbles against the water surface. Attempts to alter their size and distribution by insertion of various

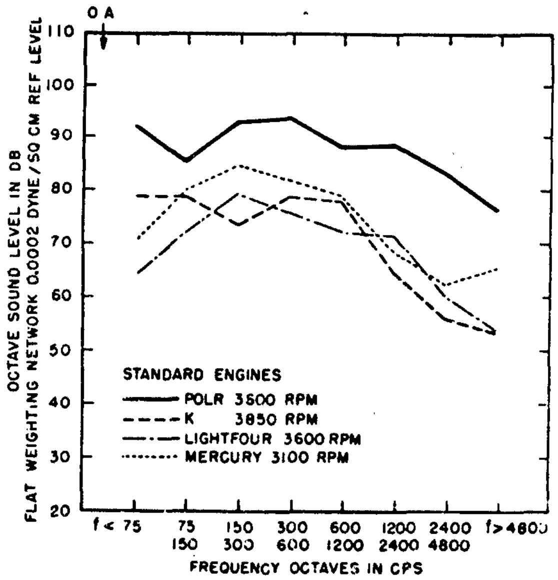

FIGURE 1. Comparison of sound levels of standard engines.

plates and auxiliary expanding chambers were quite unsuccessful. The dragging of a blanket on the surface of the water also was without effect. Even a muffler five times the normal volume produced only minor improvements in this characteristic burble. The source of this difficulty was never accurately placed, in spite of underwater sound measurements, and the motor was finally abandoned as incapable of being silenced because of this peculiarity. It was the only failure among the motors.

In the Evinrude Lightfour, a high percentage of noise was lost in the underwater exhaust in and above the slip stream of the propeller. Slight additions to the standard motor consisted of mufflers based on either a tube connecting annular chambers between washers equally spaced or a similar tube containing rolls of copper screening to provide quick cooling of the exhaust cases. The Evinrude exhaust system made use of a relief, which passed a small percentage of exhaust during starting and idling. At full speeds this passage was flooded with water and the exhaust was entirely underwater. In the Mercury, this escape feature provided so much relief that the underwater feature was entirely ineffective, and it was necessary to design a new exhaust manifold incorporating the Evinrude exhaust relief. The results were gratifying.

23.3.2 Intake

The second largest source of noise came from the carburetor intake. This was effectively silenced, in the case of all motors, by the use of a single-chamber resonant type silencer, which was attached to the in-

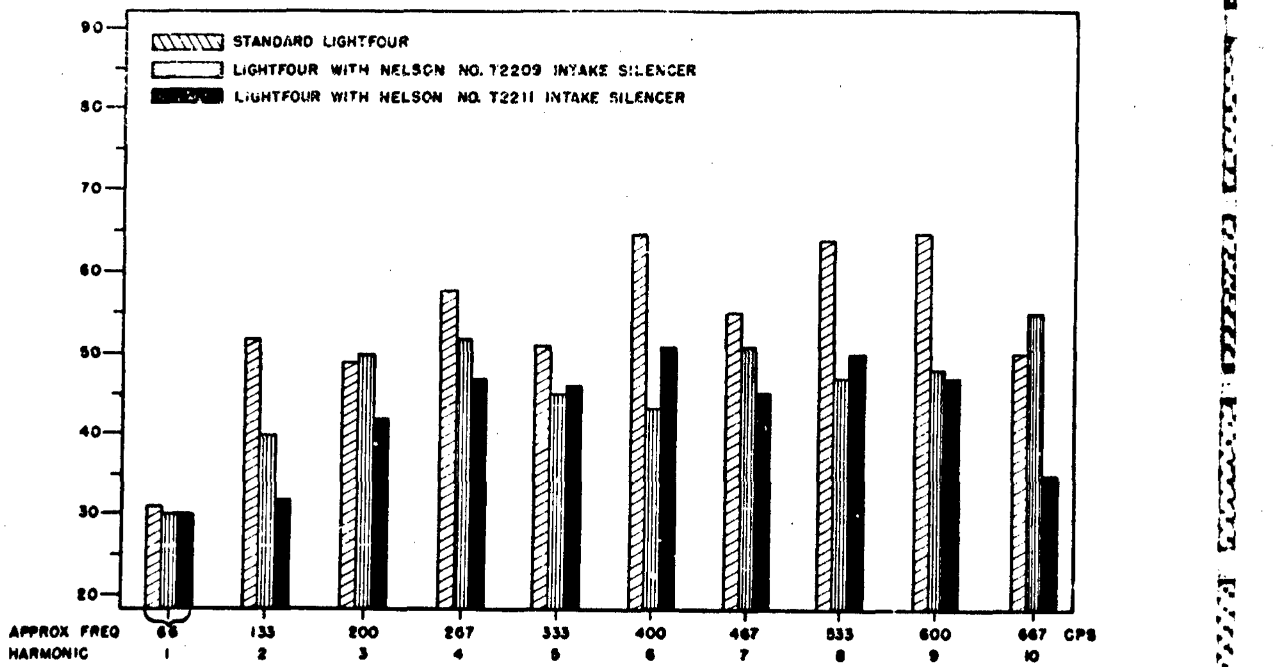

FIGURE 2. Noise level in 5-cycle band in decibels at 46 feet.

take manifold. Figure 2 shows the performance on the Evinrude Lightfour of two different models of intake silencers. A considerable reduction at all harmonic frequencies is apparent.

23.3.3 Mechanical

It seemed obvious that one would attempt the silencing of an outboard motor by enclosing the body as completely as possible in a housing. Several attempts were made, including wooden and plastic housings filled with insulating materials such as glass wool, felt, and special acoustic fillings. At the same time, less cumbersome tailor-made jackets called Barneys were tried which were intended to accomplish the same purpose but which were not so bulky. It was found that the more elaborate housings were somewhat superior in noise reduction, but not sufficiently so to warrant their use in preference to the Barneys, which were included in the kits sent to the field. A typical Barney is illustrated in Figure 3.

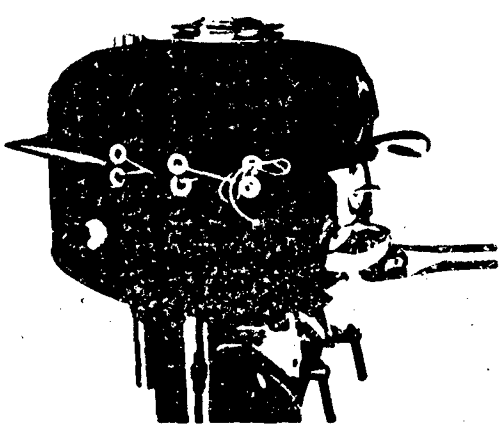

FIGURE 3. Barney.

The Barneys were tailored to fit the individual power heads and were supported over hot spots of the motor by a shroud of perforated sheet aluminum. Coverage was made as complete as possible by lacing, and sound absorption was accomplished by lining with glass wool or acoustic felt; the outer material was glass cloth. The effectiveness of a typical Barney can be seen from Figure 4.

23.4 RESULTS

The microphone tests showed that there was a directional pattern of motor noise and that noise levels would be somewhat higher in positions directly on either side of the boat with the least noise reaching an observer directly in front of the approaching boat. These differences, however, were too small to be significant. When all three of the methods of quieting were applied to all motors, the following maximum noise reduction was obtained:

TABLE 2. Maximum noise reduction on quieting of outboard motors.

Motor	Noise level at 25 ft Unsilenced	Noise level at 25 ft Silenced	Noise reduction
Johnson POLR 22 hp	95 db	69 db	26 db
Johnson K 9.8 hp	79 db	74 db	5 db
Evinrude Lightfour 9.7 hp	76 db	63 db	13 db
Mercury 6 hp	80 db	59 db	26 db

This clearly shows the success which attended all the silencing work with the exception of the Johnson K motor, which was abandoned. The figures were obtained using a 40-db weighting net.

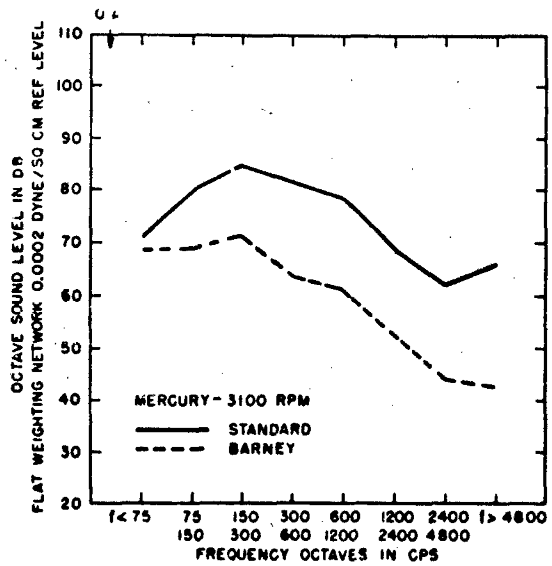

FIGURE 4. Comparison between sound level of a standard engine with and without Barney.

The difference in sound detection with different engine speeds was remarkable. Thus, in the presence of surf noise, quieted engines were undetected by listeners at 100 yd, when proceeding at a slow speed, but were detected at 300 yd at full speed. It was not clear whether the noise detection was caused by the motor or by the considerable noise created by the boat in the waves. Listening conditions such as wind direction, air temperature, and ambient noise level would, of course, vary with resultant variance in performance. It was felt, however, that the POLR, for

example, could approach, without being heard, to approximately 1,400 ft at full throttle and 280 ft at dead slow speed.

The performance obtained with the 50-hp Evinrude and 32-ft surf-landing boats using an improved Barney, an improved intake silencer, underwater exhaust, and some attempted isolation of the motor from the stern of the boat gave comparable results. A maximum reduction in noise of 54 db was obtained, and it was calculated that with a background noise of 64 db such a boat could approach to a distance of 150 yd before being detected above the ambient noise conditions.[7]

Sample kits suitable for the silencing of the three successful motors originally proposed for study were dispatched to the field, and a small production undertaken by OSS. Information was also supplied on easy starting of outboard motors,[5] since this too was a problem with the users of the motors on reconnaissance missions.

GLOSSARY

AC DELAY. Acetone Celluloid time delay.

ADHESIVE. Material used for the attachment of explosive charges.

ALCOA. Aluminum Company of America.

ARB. Army Rescue Boat.

BARNEY. A glass-cloth padded jacket for covering outboard motors.

BEANO. A baseball hand grenade filled either with high explosive or white phosphorus.

BURSOLINE. Triglycine hydrotiiodide, a compound for water purification.

C-DC. Chlor-dechlor tablets for water purification.

CITY SLICKER. An oil slick igniter.

CLOCKWORK. Precise waterproof time delays.

CORDURA. A regenerated cellulose fiber.

CSR. City Slicker, rectangular.

CST. City Slicker, triangular.

DOG DRAG. A device for throwing bloodhounds off the trail of an agent.

FBI. Fast Burning Incendiary.

IFL. Induction Field Locator, an electromagnetic device on which men equipped with IFT could home.

IFT. Induction Field Transceiver, an electromagnetic device for short range secret communication.

ISRB. Inter-Services Research Bureau, British counterpart to the Office of Strategic Services.

KOFQR. Cough Mixture, an alloy of sodium and potassium suspended in benzene in a frangible glass container.

LULU. A disperser-igniter for inflammable dusts.

MATCHHEAD. A waterproof attachment for the Pencil time delay giving silent ignition of incendiary devices.

MRL. Maryland Research Laboratories, the central laboratory of Division 19.

MWT. Microwave transmitter, a device for secure communications over short distances.

OSS. The Office of Stragetic Services.

PAUL REVERE. An incendiary functioning either on land or on water and capable of igniting crude oil as well as more combustible materials.

PENCIL. A chemical time delay for activation of explosive or incendiary devices or charges.

PERMANENTE MIX. Incendiary filling of the City Slicker and Paul Revere.

PR. Paul Revere, a form of the City Slicker.

PVC. Polyvinyl chloride; tubes in which Pencils were packaged.

RD-44-41 AND RD-43-141. Compositions of adhesives.

SALEX. A Slow Burning Explosive composed of sulfur, aluminum, and TNT.

SBX. Slow Burning Explosives.

SLEEPING BEAUTY. A one-man underwater craft developed by ISRB.

SPIGOT MORTAR. A silent flashless weapon developed by ISRB.

SR. Signal Relay (Time Pencil).

SRA. Signal Relay American.

SRI. Signal relay incendiary.

SSR. Spin stabilized rocket.

SYMPATHETIC FUZE. A device for activating one explosive charge by the firing of another.

UWT. Telegraph and telephone devices for communicating under water.

WP BEANO. Beano filled with white phosphorus.

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OSRD APPOINTEES

DIVISION 19

Chief

Harris M. Chadwell

Technical Aide

Warren C. Lothrop

Members

J. C. Boyce
L. H. Farinholt
T. R. Hogness
F. L. Hovde
R. W. King
G. B. Kistiakowsky
P. E. Klopsteg

SECTION 19.1

Chief

George A. Richter

Technical Aide

Warren C. Lothrop

Members

Harris M. Chadwell
Arthur B. Lamb
Warren C. Lothrop

CONTRACT NUMBERS, CONTRACTORS, AND SUBJECT OF CONTRACTS

Contract Number	*Name and Address of Contractor*	*Subject*
OEMsr-1023	Arthur D. Little, Inc., Cambridge, Massachusetts	Development and testing of psychological weapons
OEMsr-850	Bakelite Corporation, Bloomfield, New Jersey	Development and testing of adhesives, including underwater adhesives
OEMsr-1254	Eastman Kodak Company, Rochester, New York	Development of a hand grenade — Beano
OEMsr-1325	E. I. duPont de Nemours & Company, Wilmington, Delaware	Studies and investigations in connection with delayed-action detonators
OEMsr-955	Ford, Bacon & Davis, Inc., New York, New York	Establishment, equipment, staffing, and management of a central laboratory for testing and proving purposes in connection with the work of Division 19
OEMsr-927	Holmes Electric Protective Company, New York, New York	Development of various types of sympathetic and vibration fuzes, including relays
OEMsr-876	Leeds and Northrup Company, Philadelphia, Pennsylvania	Studies and investigations in connection with controlled delays
OEMsr-1279	Merz Engineering Company, Indianapolis, Indiana	Production design of Spigot Mortar
OEMsr-1427	Outboard, Marine & Manufacturing Company, Waukegan and Evanston, Illinois	Studies on silencing of marine engines
OEMsr-1119	Universal Match Corporation, St. Louis, Missouri	Development of a special matchhead for use in delayed-action pocket incendiaries
OEMsr-739	Galvin Manufacturing Company, Chicago, Illinois	Studies and experimental investigations in connection with the construction of amplifiers and their associated mechanisms
OEMsr-1158 (with Division 13, NDRC)	Western Electric Company, Inc., New York, New York	Studies and experimental investigations in connection with the construction of a radio-controlled switch
OEMsr-824	Willard Storage Battery Company, Cleveland, Ohio	Studies and experimental investigations in connection with the development and improvement of an electrolytic cell
OEMsr-545	Columbia University, New York, New York	Studies of the rates of reaction of iron with copper solution at different temperatures and of related problems in connection with controlled action
OEMsr-572	Harvard University, Cambridge, Massachusetts	Development of protective coating for water soluble wire
OEMsr-1214	Harvard University, Cambridge, Massachusetts	Development of specially operated incendiary and pyrotechnic devices.
OEMsr-602	University of Chicago, Chicago, Illinois	Development of devices for the destruction of materials and the development of other offensive weapons
OEMsr-922	University of Pennsylvania, Philadelphia, Pennsylvania	Investigation of secret signaling and communication devices

SERVICE PROJECT NUMBERS

The projects listed below were transmitted to the Executive Secretary, NDRC, from the War or Navy Department through either the War Department Liaison Officer for NDRC or the Office of Research and Inventions (formerly the Coordinator of Research and Development), Navy Department.

Service Project Number	*Subject*
OD-176	White Phosphorus Grenade
NR-109	Bushmaster
NO-234	Oil Slick Igniters

Other projects, forming the major portion of Division 19's program, were received directly from the Office of Strategic Services.

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